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THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

EDITED BY

GEORGE E. HALE
Mount Wilson Solar Observatory of the Carnegie Institution of Washington

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Yerkes Observatory of the University of Chicago

HENRY G. GALE
Major, U.S.A. in France

DECEMBER 1918

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THE
ASTROPHYSICAL JOURNAL
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VOLUME XLVIII DECEMBER 1918 NUMBER 5

THE RADIAL VELOCITIES OF 119 STARS OBSERVED AT THE CAPE

By JOSEPH LUNT

In continuation of radial velocity work carried on with the 24-inch refractor (Victoria telescope) and the four-prism stellar spectrograph with long camera up to May, 1908, published in the *Annals of the Royal Observatory, Cape of Good Hope*, **10**, Parts 1 and 3, a new working list containing 365 stars was brought into use in July of that year.

The program extended the magnitude down to 4.5 and embraced both northern and southern stars of types A to M*b*. The brighter stars down to about magnitude 3.7 were observed with a narrower slit than were the fainter ones, and the present paper gives the radial velocities of 119 of these brighter stars in a condensed form pending a more detailed account of the work contemplated when conditions become more normal.

A considerable number of these stars (33) classified as of types A and F were abandoned, as the spectra with the dispersion employed proved to be unsuitable for accurate measurement. A list of these is given in Table VI. The velocities of the fainter stars which, with the wider slit, gave more diffuse spectra will be dealt with in a subsequent communication. As the instrument and methods of work have been fully described in the publications

referred to and in Sir David Gill's *History and Description of the Cape Observatory*, it is unnecessary to say more than that an iron spark, diffused by a ground-glass screen placed in front of the slit, was employed throughout as the source of the comparison spectrum, and that the measures were made with a Hartmann spectrocomparator. The region measured was between the iron lines:

λλ 4118.7–4528.8	in the case of	α	Can. Min.,	standard	2147
4315.3–4584.0	"	"	"	" α Tauri,	standard 2145
4337.2–4528.8	"	"	"	" Solar	standards
4427.5–4603.1	"	"	"	" α Boötis,	standard 1191
4427.5–4603.1	"	"	"	" α Tauri,	standard 1110

The photographic work was completed at the end of 1916.

The measures were made by the writer except where otherwise stated. In some cases plates remeasured by Halm or measured by him alone are included in the mean velocities given in Table III.

The stars here dealt with are divided into two classes: 76, which appear to have constant velocities, and 43, which are either known or suspected to be spectroscopic binaries showing variable radial velocities.

Eighteen stars in the first class were very frequently observed with a view to a continuation of the solar parallax work, and as these give the best criterion of the accuracy attained, the results for these stars are given separately in Table I.

Out of the total of 1269, 561 plates of the spectra of these 18 stars were measured and 9 were rejected for abnormal discordance, the discordant velocities being given in the last column of Table I.

The table shows that for the stars of early type (α Can. Min. and π Sagittarii), in which it was possible to extend the measures into the region of shorter wave-length and larger scale, the probable error of the velocity given by a single plate was about half a kilometer and that for the stars of later type (α Arietis and α Tauri) and the solar stars 0.75 km.

The probable error of the derived velocities was 0.1 km for the early-type stars and 0.15 km for solar and later-type stars.

Of these 552 plates, 98 per cent show discordances from the means of the groups of 2.5 km or less; 94 per cent show a discordance from 0.0 to 2.0 km. It is difficult to fix the point where these

TABLE I

Cape List Number	Star	Extent of Period in Days	Middle Date	No. of Plates Included	Radial Velocity in Km	Probable Errors Km		Lick Radial Velocity Km	Lick *minus* Cape Km	Plates Rejected	Rejected Velocities
						Of Velocity *R*	Of 1 Plate *r*				
9.....	β Ceti.....	1583	1910.80	49	+12.8	±0.11	±0.77	+14.6	+1.8	2	+17.5, 1909, June 21 9.4, 1912, July 7
24.....	α Arietis*.....	1622	" .84	35	−15.3	.14	.84	−14.0	+1.3	0	
56.....	α Tauri*.....	1633	" .58	56	+54.0	.09	.65	+55.1	+1.1	1	+56.2, 1911, Feb. 5
108.....	α Can. Min.*...	1577	" .99	45	− 3.6	.06	.39	− 3.5	+0.1	0	
112.....	β Geminorum...	1085	1911.32	27	+ 3.2	.15	.76	+ 3.9	+0.7	0	
143.....	α Hydrae.....	1104	1910.86	32	− 4.6	.16	.92	− 3.5	+1.1	0	
187.....	ε Corvi.....	1281	" .73	28	+ 5.6	.15	0.82	+ 4.8	−0.8	1	+ 0.5, 1912, Jan. 15
192.....	β Corvi.....	1272	" .77	26	− 7.8	.20	1.02	− 7.1	+0.7	0	
199.....	ε Virginis.....	1281	" .82	22	−14.3	.12	0.55	−13.2	+1.1	1	−18.3, 1912, Jan. 24
212.....	θ Centauri.....	1269	" .79	36	+ 1.4	.13	.80	+ 1.5	+0.1	0	
214.....	α Boötis.....	1485	" .61	33	− 5.3	.12	.69	− 3.9	+1.4	0	
234.....	α Serpentis.....	1299	" .90	26	+ 2.9	.15	.75	+ 3.4	+0.5	2	− 0.9, 1909, Feb. 15 1.7, 1909, Mar. 1
253.....	ε Scorpii.....	1138	1911.20	24	− 1.9	.12	.88	− 2.2	−0.3	0	
283.....	δ Sagittarii	1429	1910.71	21	−20.1	.17	.77	−20.2	−0.1	0	
287.....	λ Sagittarii.....	1327	" .48	15	−43.4	.11	.52	−43.1	+0.3	1	−46.5, 1908, Aug. 31
299.....	π Sagittarii*....	1381	" .48	21	−10.1	.12	.53	−10.5	−0.4	0	
327.....	β Aquarii.....	1486	" .80	30	+ 5.6	.15	.81	+ 6.9	+1.3	0	
335.....	α Aquarii.....	1499	" .82	26	+ 6.8	0.14	0.73	+ 7.5	+0.7	1	+ 9.7, 1912, Nov. 13
Total....	18 stars	.....	.....	552	Means.	±0.13	±0.73	.....	+0.6	9	.....

* Solar (daylight) standard plates used for all stars except 24 and 56 (α Tauri, standard 2145) and 108 and 229 (α Can. Min., standard 2147).

results for radial velocity should be considered to show a real variation, but we may fix 5 km as a "range," that is, difference between highest and lowest values, which is on the border line. The mean

TABLE II

(The subscript after the velocities denotes the number of plates used)

H. R. No.	Star	Rad. Vel. (1) Cape	Rad. Vel. (2) D. O. Mills	Diff. (2)−(1)	Range	
					Cape	D. O. Mills
		km	km	km	km	km
98	β Hydri	$+21.7_6$	$+23.0_5$	+1.3	1.9	0.6
322	β Phoenicis	-0.8_6	-1.2_6	−0.4	3.2	1.8
1208	γ Hydri	$+17.6_3$	$+15.7_4$	−1.9	3.7	0.4
1829	β Leporis	-14.9_7	-13.7_5	+1.2	3.7	2.3
2040	β Columbae	$+89.3_7$	$+89.2_5$	−0.1	2.3	3.5
2326	α Argus	$+19.7_{13}$	$+20.5_{10}$	+0.8	3.6	1.1
3307	ε Carinae	$+11.2_8$	$+10.8_4$	−0.4	4.8	3.3
3347	β Volantis	$+28.8_5$	$+27.0_4$	−1.8	4.2	1.6
3634	λ Velorum	$+18.5_8$	$+18.2_5$	−0.3	2.6	1.9
3699	ι Carinae	$+13.5_6$	$+13.3_6$	−0.2	1.7	2.3
3803	N Velorum	-14.2_4	-14.2_5	0.0	2.0	1.7
3890	υ Carinae	$+13.5_3$	$+13.9_5$	+0.4	0.3	2.3
4630	ε Corvi	$+5.6_{28}$	$+4.8_6$	−0.8	5.6	1.4
4763	γ Crucis	$+20.4_7$	$+20.6_4$	+0.2	2.2	2.0
4786	β Corvi	-7.8_{26}	-7.5_4	+0.3	5.3	2.1
5287	π Hydrae	$+27.8_6$	$+27.4_4$	−0.4	2.4	2.9
5288	θ Centauri	$+1.4_{36}$	$+2.0_4$	+0.6	4.7	2.1
5463	α Circini	$+7.6_6$	$+7.7_4$	+0.1	2.5	0.9
5649	ζ Lupi	-8.9_3	-10.0_4	−1.1	1.7	1.8
5705	φ′ Lupi	-28.1_3	-30.4_4	−2.3	2.2	2.2
6217	α Triang. Aust	-4.0_8	-3.2_4	+0.8	2.7	1.2
6241	ε Scorpii	-1.9_{24}	-2.2_4	−0.3	4.5	2.4
6285	ζ Arae	-5.6_3	-6.3_4	−0.7	0.9	1.3
6461	β Arae	$+0.9_3$	-1.2_4	−2.1	1.6	1.1
6630	G Scorpii	$+25.0_3$	$+24.5_4$	−0.5	0.4	2.3
6832	η Sagittarii	0.0_3	$+0.2_4$	+0.2	1.8	2.2
6859	δ Sagittarii	-20.1_{21}	-19.7_2	+0.4	3.6	0.2
6913	λ Sagittarii	-43.4_{15}	-43.2_2	+0.2	2.0	0.6
7264	π Sagittarii	-10.1_{21}	-11.9_2	−1.8	3.1	1.6
7665	δ Pavonis	-22.8_3	-22.6_5	+0.2	2.7	3.6
7869	α Indi	$+0.1_6$	-1.6_4	−1.7	3.0	1.0
7986	β Indi	-6.2_2	-6.6_4	−0.4	0.4	2.0
8636	β Gruis*	$+1.2_8$	$+0.6_6$	−0.6	5.1	3.7
Total	33 stars	No. of plates 311	No. of plates 147		Mean range 2.8	Mean range 1.9

*Strongly suspected of variability by Wright (see *Publications of the Lick Observatory*, 9, 315).

"range" for the 76 stars is 2.9 km; the highest values are 5.6, 5.3 (two), 5.1 (two) (see Table III).

As the period of observation is extended, some of these 76 stars may prove to be binaries. It would be easy to pick out series of

TABLE III

Cape List No.	H.R. No.	Star	α 1900	δ 1900	Mag.	Type	Standard Plates Used	No. of Plates	Mean Epoch	Radial Velocities Km		Range Km	Diff. (1)–(2) Km	Remarks
										Lick* (1)	Cape (2)			
2....	74	ι Ceti.....	0h14m3	− 9°23′	3.75	K	⊙	6	1910.4	+18.8	+18.8	3.5	0.0	
4....	98	β Hydri.....	20.5	−77 49	2.90	G	⊙	6	1910.5	+22.8	+21.7	1.9	+1.1	
9....	188	β Ceti.....	38.6	−18 32	2.24	K	⊙	49	1910.8‡	+14.6	+12.8	4.1	+1.8	$c+13.8_4$
12....	322	β Phoenicis....	1 1.6	−47 15	3.35	K	⊙	6	1910.6	− 0.5	− 0.8	3.2	+0.3	
13....	334	η Ceti.....	3.6	−10 43	3.60	K	⊙	5	1909.8	+11.6	+12.0	2.0	−0.4	
16....	437	η Piscium.....	26.1	+14 50	3.72	G5	⊙	5	1909.2	+15.5	+15.5	4.4	0.0	(6) $\begin{cases} e+14.8_4 \\ c+13.8_4 \end{cases}$
17a...	509	τ Ceti.....	39.4	−16 28	3.65	K	2145	4	1913.7	−15.5	−16.4	2.5	+0.9	
24....	617	α Arietis†.....	2 1.5	+22 59	2.23	K_2	2145	35	1910.8‡	−14.0	−15.3	5.3	+1.3	(1) (16)
25....	681	ο Ceti (Mira)..	14.3	− 3 26	var.	Md	2145	5	1916.0	+62.3	+63.4	5.1	−1.1	$(9a)c+65.1_3$
31....	911	α Ceti†.....	57.1	+ 3.42	2.82	Ma	2145	10	1909.0	−25.1	−25.4	2.6	+0.3	$c-24.4_4$
37....	1084	ε Eridani.....	3 28.2	− 9 48	3.81	K	⊙	5	1908.9	+16.5	+14.8	2.0	+1.7	
42....	1208	γ Hydri.....	48.8	−74 33	3.17	Ma	2145	3	1912.9	+16.	+17.6	3.7	−1.6	
43....	1231	γ Eridani.....	53.4	−13 48	3.19	K5	⊙	7	1909.8	+62.5	+62.0	1.5	+0.5	
56....	1457	α Tauri†.....	4 30.2	+16 19	1.06	K5	2145	56	1910.6‡	+55.1	+54.0	4.2	+1.1	(7a) $\begin{cases} a+54.1_5 \\ c+55.1_7 \end{cases}$
64....	1654	ε Leporis.....	5 1.2	−22 30	3.29	K5	2145	5	1909.6	+ 1.1	+ 1.1	2.7	0.0	
66....	1829	β Leporis†.....	24.0	−20 50	2.96	G	⊙	7	1910.5	−13.7	−14.9	3.7	+1.2	$b-12.4_2$
68....	1865	α Leporis.....	28.3	−17 54	2.69	F	2147	10	1909.2	+24.9	+24.3	3.6	+0.6	
76....	2040	β Columbae†...	47.4	−35 48	3.22	K	1191	7	1910.3	+89.2	+89.3	2.3	−0.1	(3a)
84....	2286	μ Geminorum..	6 16.9	+22 34	3.19	Ma	2145	2	1913.2	+54.6	+56.5	1.3	−1.9	$c+56.0_3$
86....	2326	α Argus†.....	21.7	−52 38	0.86m	F	2147	13	1909.2	+20.8	+19.7	3.6	+1.1	(15)
101....	2773	π Puppis†.....	7 13.6	−36 55	2.74	K5	2145	7	1909.9	+16.4	+16.2	1.5	+0.2	
108....	2943	α Can. Min.†...	34.1	+ 5 29	0.48	F5	2147	45	1911.0‡	− 3.5	− 3.6	2.1	+0.1	$c-4.6_7$
111....	*2985	κ Geminorum..	38.4	+24 38	3.68	G5	⊙	3	1913.8	+20.3	+21.3	0.3	−1.0	$\begin{cases} a+19.9_2 \\ c+20.7_4 \end{cases}$
112....	2990	β Geminorum†	39.2	+28 16	1.21	K	⊙	27	1911.3‡	+ 3.9	+ 3.2	3.9	+0.7	(17)
124....	3307	ε Carinae†.....	8 20.5	−59 11	1.74	Kp	⊙	8	1910.0	+12.	+11.2	4.8	+0.8	
127....	3347	β Volantis.....	24.6	−65 48	3.65	K	⊙	5	1911.2	+28.	+28.8	4.2	−0.8	
135....	3547	ζ Hydrae.....	50.1	+ 6 20	3.30	K	⊙	6	1910.4	+23.1	+22.7	4.6	+0.4	$c+23.2_3$
139....	3634	λ Velorum†....	9 4.3	−43 2	2.22	K5	2145	8	1910.4	+19.2	+18.5	2.6	+0.7	
142....	3699	ι Carinae†.....	14.4	−58 51	2.25	F	2147	6	1910.7	+13.3	+13.5	1.7	−0.2	
143....	3748	α Hydrae†.....	22.7	− 8 14	2.16	K2	⊙	32	1910.9‡	− 3.5	− 4.6	5.1	+1.1	$c-3.5_1$
145....	3803	N Velorum†....	28.2	−56 36	3.04	K5	2145	4	1910.9	−13.5	−14.2	2.0	+0.7	
149....	3873	ε Leonis	40.2	+24 14	3.12	Gp	⊙	3	1912.5	+ 5.0	+ 5.0	2.8	0.0	$c+4.9_5$
150....	3890	ν Carinae†.....	44.6	−64 36	3.15	F	2147	3	1912.8	+13.8	+13.5	0.3	+0.3	
168....	4216	μ Velorum†....	10 42.5	−48 54	2.84	G5	⊙	5	1910.0	+ 7.4	+ 7.1	2.3	+0.3	(10)
169....	4232	ν Hydrae.....	44.7	−15 40	3.32	K	2145	3	1912.2	− 1.1	− 0.3	1.9	−0.8	
182....	4540	β Virginis.....	11 45.5	+ 2 20	3.80	F8	⊙	5	1911.2	+ 4.9	+ 4.1	1.9	+0.8	$\begin{cases} a+6.4_6 \\ c+3.9_4 \end{cases}$

TABLE III—*Continued*

Cape List No.	H.R. No.	Star	α 1900	δ 1900	Mag.	Type	Standard Plates Used	No. of Plates	Mean Epoch	Radial Velocities Km		Range Km	Diff. (1)–(2) Km	Remarks
										Lick* (1)	Cape (3)			
187....	4630	ε Corvi.....	12 5.0	−22 4	3.21	K	⊙	28	1910.7‡	+ 4.8	+ 5.6	5.6	−0.8	
190....	4763	γ Crucis†.....	25.6	−56 33	1.61	Mb	2145	7	1910.2	+22.	+20.4	2.2	+1.6	
192....	4786	β Corvi†.....	29.1	−22 51	2.84	G5	⊙	26	1910.8‡	− 7.1	− 7.8	5.3	+0.7	
199....	4932	ε Virginis.....	57.2	+11 30	2.95	K	⊙	22	1910.8†	−13.2	−14.3	3.2	+1.1	{a −12.2₈ c −13.5₈
201....	5020	γ Hydrae.....	13 13.5	−22 39	3.33	G5	⊙	6	1910.4	− 5.6	− 4.5	3.4	−1.1	
211....	5287	π Hydrae.....	14 0.7	−26 12	3.48	K	⊙	6	1910.3	+27.3	+27.8	2.4	−0.5	
212....	5288	θ Centauri†....	0.8	−35 53	2.26	K	⊙	36	1910.8‡	+ 1.5	+ 1.4	4.7	+0.1	
214....	5340	α Boötis†.....	11.1	+19 42	0.24	K	⊙	33	1910.6‡	− 3.9	− 5.3	4.4	+1.4	(7) (18)
218....	5463	α Circini.....	34.4	−64 32	3.41	F	2147	6	1911.5	+ 7.0	+ 7.6	2.5	−0.6	
221....	5506	ε Boötis.....	40.6	+27 30	2.70	K	⊙	3	1911.8	−16.4	−16.1	3.2	−0.3	(5) {a −17.3₅ c −15.0₆
223....	5603	σ Librae.....	58.2	−24 53	3.41	Mb	2145	3	1913.2	− 3.5	− 4.9	1.1	+1.4	
224....	5649	ζ Lupi.....	15 5.1	−51 43	3.50	K	⊙	3	1911.0	− 9.4	− 8.9	1.7	− 0.5	
226....	5705	φ¹ Lupi.....	15.5	−35 54	3.59	K5	2145	3	1913.2	−30.2	−28.1	2.2	−2.1	
234....	5854	α Serpentis....	39.3	+ 6 44	2.75	K	⊙	26	1910.9‡	+ 3.4	+ 2.9	4.6	+0.5	{a +4.1₂ c +3.7₀
245....	6075	ε Ophiuchi.....	16 13.0	− 4 27	3.34	K	⊙	5	1910.9	− 9.2	− 9.3	2.3	+0.1	(11)
251....	6217	α Triang. Aust.†	38.1	−68 51	1.88	K2	2145	8	1910.6	− 3.6	− 4.0	2.7	+0.4	(18)
253....	6241	ε Scorpii†.....	43.7	−34 7	2.36	K	⊙	24	1911.2‡	− 2.2	− 1.9	4.5	−0.3	
255....	6285	ζ Arae.....	50.3	−55 50	3.06	K5	2145	3	1913.8	− 6.6	− 5.6	0.9	−1.0	
259....	6299	κ Ophiuchi.....	52.9	+ 9 32	3.42	K	2145	3	1914.3	−55.9	−54.7	4.3	−1.2	(8) c −54.7₄
261....	6406	α Herculis.....	17 10.1	+14 30	3.48	Mb	2145	3	1914.3	−32.2	−32.4	1.1	+0.2	
262....	6461	β Arae.....	17.0	−55 26	2.80	K2	2145	3	1913.5	− 1.2	+ 0.9	1.6	−2.1	
270....	6603	β Ophiuchi†....	38.5	+ 4 37	2.94	K	2145	6	1909.4	−11.8	−11.2	2.8	−0.6	(9) {b −11.1₃ c −11.4₆
272....	6623	μ Herculis.....	42.5	+27 47	3.48	G5	2145	3	1916.7	−15.6	−15.9§	2.9	+0.3	c −15.5₄
273....	6630	G Scorpii.....	43.0	−37 1	3.25	K2	2145	3	1913.2	+24.5	+25.0	0.4	−0.5	
274....	6698	ν Ophiuchi.....	53.5	− 9 46	3.50	K	2145	6	1912.5	+12.9	+12.7	2.2	+0.2	(18)
281....	6832	η Sagittarii....	18 10.9	−36 47	3.16	Mb	2145	3	1912.0	0.0	0.0	1.8	0.0	
283....	6859	δ Sagittarii....	14.6	−29 52	2.84	K	⊙	21	1910.7‡	−20.2	−20.1	3.6	−0.1	
287....	6913	λ Sagittarii....	21.8	−25 29	2.94	K	⊙	15	1910.5‡	−43.1	−43.4	2.0	+0.3	
291....	7150	ξ² Sagittarii....	51.8	−21 14	3.61	K	⊙	4	1911.5	−19.9	−19.4	1.2	−0.5	(2)
299....	7264	π Sagittarii....	19 3.8	−21 11	3.02	F2	2147	21	1910.5‡	−10.5	−10.1	3.1	−0.4	
304....	7525	γ Aquilae.....	41.5	+10 22	2.80	K2	⊙	4	1909.2	− 1.9	− 3.0	2.6	+1.1	
310....	7635	γ Sagittae.....	54.3	+19 13	3.71	K5	2145	3	1916.4	−33.8	−31.6§	2.9	−2.2	
311....	7665	δ Pavonis.....	58.9	−66 26	3.64	G5	⊙	3	1913.0	−21.7	−22.8	2.7	+1.1	{b −1.8₃ c −1.6₇

315....	7869	α Indi.....	20 30.5	−47 38	3.21	K	⊙	6	1911.6	− 1.7	+ 0.1	3.0	−1.8	
321....	7986	β Indi.....	47.0	−58 50	3.72	K	⊙	2	1910.1	− 6.2	− 6.2	0.4	0.0	(12)
327....	8232	β Aquarii.....	21 26.3	− 6 1	3.07	G	⊙	30	1910.8‡	+ 6.9	+ 5.6	4.1	+1.3	(14) c+5.7$_4$
330....	8308	ϵ Pegasi.....	39.3	+ 9 25	2.54	K	1191	10	1909.3	+ 5.0	+ 4.8	3.4	+0.2	(3, 19)
335....	8414	α Aquarii.....	22 0.6	− 0 48	3.19	G	⊙	26	1910.8‡	+ 7.5	+ 6.8	4.2	+0.7	c+5.9$_4$
342....	8636	β Gruis†.....	36.7	−47 24	2.24	Mb	1110	8	1910.1	+ 1.2	+ 1.2	5.1	0.0	a)
356....	8812	c^2 Aquarii.....	23 4.1	−21 43	3.80	K	⊙	5	1908.9	+21.2	+21.4	2.0	−0.2	
		76 stars					Total..	852			Means...	2.9	+0.09	

* W. W. Campbell, "The Radial Velocities of 915 Stars," *Lick Observatory Bulletins*, **7**, 113.

† Previously observed at the Cape; see *Annals of the Cape Observatory*, **10**, Parts I and III.

‡ Middle date.

§ Measures by Halm.

a Emerson McMillin (correction −1.8 km applied), Lord and Maag, 12.5-inch refractor, *Astrophysical Journal*, **21**, 313, 1905.

b Yerkes, Frost and Adams, 40-inch refractor, *Astrophysical Journal*, **18**, 273, 1903.

c Bonn (correction −1.0 km applied), Küstner and Zurhellen, 30 cm refractor, *Astrophysical Journal*, **27**, 301, 1908.

(1), (1*a*), and (1*b*), 7, 2, and 3 plates measured with 1191 standard included respectively.

(2) and (4), 2 and 3 plates measured with 2145 standard included respectively.

(3) and (3*a*), 3 and 2 plates measured with solar standard included respectively.

(3) and (3*a*), 1 plate measured with 2145 standard included in each case.

(4*a*), Strongly suspected of variability by Wright (see *Publications of Lick Observatory*, **9**, 315, 19 plates, range, 5.8 km.)

(5), ϵ Boötis is suspected to be variable. Zurhellen's measures, 5 plates, range, 6.4 km (see *Astrophysical Journal*, **27**, 313, 1908), but it has not been included in Campbell's second list of binaries and is not noted in his list of 915 stars.

(6), η Piscium is suspected to be variable. Maag's measures, 4 plates, range, 6.6 km (see *Astrophysical Journal*, **21**, 313, 1905).

(7), α Boötis, 31 plates at Mount Wilson (Adams) give −4.3 km (see *Astrophysical Journal*, **42**, 186, 1915, and *ibid.*, **31**, 379, 1910). (Frost.)

(7*a*), α Tauri, 16 plates at Mount Wilson (Adams) give +54.0 km (see *Astrophysical Journal*, **42**, 186, 1915).

(8), κ Ophiuchi, 1 plate measured with solar standard gives for 1910, August 1, −57.3 km (included).

(9), β Ophiuchi, 3 plates measured with solar standards and 3 with 1191; duplicate measures of four plates by Halm with standard 2145 included.

(9*a*) o Ceti (Mira) velocity from absorption lines. See also *Astrophysical Journal*, **18**, 354, 1903 (+62.7 km) and *Jour. of Roy. Astro. Soc. Canada*, **1**, 50, 1907 (+65.5 km).

(10), rejected plates, Star No. 168, μ Velorum, Plate 2942, 1911, January 2, +12.0.

(11), rejected plates, Star No. 245, ϵ Ophiuchi, Plate 3638, 1912, June 1, −20.5.

(12), rejected plates, Star No. 321, β Indi, Plate 3223, 1911, July 10, −0.2 faint star spectrum.

Particulars of nine other rejected plates are given in Table I.

(14), β Aquarii, 7 plates measured in duplicate with solar and α Can. Min. 2147 standards give +6.5 km and +6.3 km, respectively. Dates, 1912, June 4 to November 1.

(15), duplicate measures of 7 plates by Halm and Lunt give respectively +19.2 and +19.6 km.

(16) α Arietis: a −14.2$_3$, b −13.7$_1$, c −13.8$_4$

(17) β Geminorum: a +3.5$_3$, b +3.4$_3$, c +3.8$_{10}$

(18) α Boötis: a −5.5$_7$, b −4.8$_3$, c −4.9$_6$

(19) ϵ Pegasi: a +4.3$_3$, b +6.2$_1$, c +5.0$_3$

The subscript after the velocity indicates the number of plates measured.

plates showing a very small range over a limited period, but these give an erroneous idea of the consistency of results which would be obtained when the period is extended over several years, and this is the experience of other observatories. The stars in Table I have been observed under severe conditions, being taken at quadratures, at opposite seasons of the year, often with the telescope first on one side of the pillar and then the other, and at very various hour angles, first east and then west, and for periods extending over from 1104 to 1583 days; and moreover ten different observers took part at various times in the guiding during the exposure of the plates. These conditions were imposed mainly by the nature of the solar-parallax problem. Had the object been only radial velocities, more uniform conditions could have been employed and the consistency of results probably enhanced.

At the same time the possibility of convection in stellar atmospheres, noted by Evershed[1] and Campbell,[2] causing variations in displacements of lines, should not be overlooked.

If we regard the wide, hazy absorption lines in stellar spectra as due to convection effects in stellar atmospheres, as suggested by Campbell, it follows that any star in which the uprush of gases predominates in the hemisphere turned toward us at the time of taking a spectrogram will show an abnormal velocity of approach and vice versa.

These convection effects may thus introduce slight apparent variations in velocity which do not belong to the star as a whole, and which would be irregular in character and may account for unexplained discordances in determinations of radial velocity extending over long periods.

Summarizing from Table I, we have the following means of the probable errors, R and r being the probable errors of a mean velocity and of a single plate respectively:

			R	r
66 plates of	2 stars	α Can. Min., standard 2147	±0.09	±0.46 km
91 plates of	2 stars	α Tauri, standard 2145	±0.12	±0.75 km
395 plates of	14 stars	Solar standards	±0.14	±0.77 km
552 plates of	18 stars	Mean	±0.13	±0.73 km

[1] *Kodaikanal Observatory Bulletin*, No. 36. [2] *Lick Observatory Bulletin*, **8**, 82.

The radial velocities measured with stellar plates as standards have the further uncertainty in the assumed value of the shift of the spectrum on the standard plate, which is for

α Can. Min.	2147	Shift	− 1.22	±0.14 km
α Tauri	2145	"	+77.38	±0.14 km
α Tauri[1]	1110	"	+84.41	±0.09 km
α Boötis	1191	"	+19.03	±0.09 km

the shift being measured by comparison with 20 plates of the solar spectrum (daylight spectra) duly corrected for the earth's radial velocity with respect to the sun.

Comparison with velocities obtained at other observatories.—Radial velocities for the 76 stars of Table III have been published by Campbell in *Lick Observatory Bulletin* **7**, 114–128, representing the best values obtained from the results available from all sources. The systematic difference is +0.08 km (Lick *minus* Cape). The individual differences may be divided as follows:

	km	km	
Lick *minus* Cape	0.0 to	0.5	36 stars
	0.6 to	1.0	16
	1.1 to	1.5	15
	1.6 to	2.0	6
	2.1 to	2.2	3
			76 stars

The range of velocities for individual stars may be thus classified:

	km	km	
Range	0.0 to	2.0	23 stars
	2.1 to	3.0	21
	3.1 to	4.0	13
	4.1 to	5.0	13
	5.1 to	5.6	6
			76 stars

Thirty-three stars common to Table III and to the program of the D. O. Mills Expedition to Chile show a systematic difference of −0.3 km (Chile *minus* Cape).

[1] *Annals of the Cape Observatory*, **10**, 45 and 49.

TABLE IV

KNOWN AND SUSPECTED SPECTROSCOPIC BINARIES

Cape List No.	H.R. No.	Star	α (1900)	δ (1900)	Mag.	Type	No. of Plates 852+	Observed Range km/sec.	Published Range km/sec.	*L.O.B.* Reference
5	99	α Phoenicis*	$0^h 21^m.3$	−42° 51′	2.44	K	39	11.4	5.2	3 110¶
8	165	δ Andromedae	34.0	+30 19	3.5	K	3	4.8	9.0	7 102
20	566	χ Eridani†	1 52.0	−52 7	3.73	G5	5	8.2	.....	7 117
48	1336	α Reticuli†	4 13.1	−62 43	3.36	G5	5	6.3	.....	7 117
61	1543	π^3 Orionis†	44.4	+ 6 47	3.31	F8	6	6.6	.....	7 114
78	2061	α Orionis*	5 49.8	+ 7 23	0.92	Ma	63	8.7	.....	.....¶
86*a*	2421	γ Geminorum*	6 31.9	+16 29	1.93	A	3	22.1	13.4	.....¶
87	2473	ε Geminorum†	37.8	+25 14	3.18	G5	3	6.1	.....	7 118
88*a*	2491	α Canis Maj.	40.7	−16 35	−1.58	A	9	2.1	6.8	3 81¶
91	2553	τ Puppis	47.5	−50 30	2.83	K	8	12.6	7.3	5 60
97	2693	δ Canis Maj.*‡	7 4.3	−26 14	1.98	F8p	10	3.3	3.0	5 176
98	2736	γ^2 Volantis†	9.6	−70 20	3.87	K	4	5.7	.....	6 145
105	2878	σ Puppis	26.1	−43 6	3.27	K5	33	40.9	16.6	3 111¶
116	3045	ξ Puppis†	45.1	−24 37	3.47	G	6	8.2	.....	7 118
117	3080	*a* Puppis	48.8	−40 19	3.76	G5	7	17.5	12.	3 111¶
119	3185	ρ Puppis*	8 3.3	−24 1	2.88	F5	9	5.9	8.4	2 29
130	3445	*b* Velorum	37.3	−46 18	4.06	F5p	3	3.3	14.	8 72
133	3482	ε Hydrae	41.5	+ 6 47	3.48	F8	3	6.8	16.1	1 23¶
157	4057	γ Leonis§	10 14.5	+20 21	2.61	K	4	2.4	.....	6 24¶
178	4450	ξ Hydrae†	11 28.1	−31 18	3.72	G5	3	8.1	.....	7 118
194	4825 4826	γ Virginis	12 36.6	− 0 54	3.65 3.68	F	1 2	..... 0.0	.....	.....
209	5235	η Boötis	13 49.9	+18 54	2.80	G	8	14.4	16.7	3 85¶
216	5459	α_1 Centauri*	14 32.8	−60 25	0.33	G	22	2.3	.....	3 3¶
217	5460	α_2 Centauri*			1.70	K5	12	3.7	.....	3 3¶
243	6056	δ Ophiuchi†	16 9.1	− 3 26	3.03	Ma	5	10.5	.....	.....
247	6134	α Scorpii*	23.3	−26 13	1.22	Map	50	5.9	.....	.....¶
257	6148	β Herculis	25.9	+21 42	2.81	K	3	27.3	26.5	5 24¶
268	6561	ξ Serpentis	17 31.9	−15 20	3.64	A5	3	13.4	23.	3 85

271.....	6615	ι^1 Scorpii†.....	40.6	−40 5	3.14	F5p	4	6.1	.....	7 127
277.....	6746	γ Sagittarii.....	59.4	−30 26	3.07	K	19	4.5	6.4	6 153
284.....	6869	η Serpentis†.....	18 16.1	− 2 55	3.42	K	6	15.1	.....	7 125
295.....	7234	τ Sagittarii.....	19 0.7	−27 49	3.42	K	6	11.6	26.	3 86
303.....	7417	β Cygni.....	26.7	+27 45	3.24	Kp	3	0.7	.....	7 125¶
313.....	7754	α_2 Capricorni†.....	20 12.5	−12 51	3.77	K	3	8.8	.....	.....
314.....	7776	β Capricorni.....	15.4	−15 6	3.25	Gp	17	42.4	44.1	6 6¶
316.....	7882	β Delphini.....	32.9	+14 15	3.72	F5	3	9.1	14.1	6 148
322.....	8115	ζ Cygni.....	21 8.7	+29 49	3.40	K	4	1.7	7.1	4 97
325.....	8204	ζ Capricorni.....	21.0	−22 51	3.86	Gp	3	1.2	9.2	5 176
329.....	8278	γ Capricorni.....	34.6	−17 7	3.80	Fp	3	5.2	8.6	6 148
337.....	8502	α Toucani.....	22 11.7	−60 45	2.91	K2	8	13.5	8.7	6 152
343.....	8650	η Pegasi.....	38.3	+29 42	3.10	G	3	3.7	29.7	1 29¶
354.....	8775	β Pegasi†.....	58.9	+27 32	2.61	Mb	3	6.1	.....	7 128
Total...	.....	43 stars				Total..	1269	plates		

* Previously observed at the Cape; see *Annals of the Cape Observatory*, **10**, Plates I and III.

† The binary character of δ Ophiuchi, η Serpentis, and β Pegasi appears not to have been recorded previously, but is regarded as established. The ranges are 10.5, 15.1, and 6.1, respectively. In the last case the velocities show a further variation from the Lick and Yerkes values, total range 12.5 km. The four stars χ Eridani ξ Puppis, ξ Hydrae, and α_2 Capricorni, with ranges over 8 km per second are regarded as probably variable, while α Reticuli, π^3 Orionis, ϵ Geminorum, γ^2 Volantis, and ι^2 Scorpii, with ranges 5.7 to 6.6 are put on the suspected list. Further observations of these twelve stars will be made as opportunity occurs.

‡ Wright regards δ Canis Majoris as a binary having a period of nine months and a range of three kilometers, but it may be doubted whether observations have as yet reached sufficient accuracy to establish this conclusion, especially as this star gives unusually broad lines.

§ Burnham shows that the apparent motion of the companion is rectilinear and uniform (*Monthly Notices*, **58**, 387). γ Leonis, therefore, is not a visual binary.

¶ For other references see the following. The figures in parentheses are Cape List numbers.

(5) Orbit (Lunt) *Astrophysical Journal*, **47**, 196, 1918.
(78) Orbit (Bottlinger) *Astronomische Nachrichten*, **187**, 33, and *Astrophysical Journal*, **44**, 250.
(86*a*) Orbit (Harper) *Jour. Roy. Astron. Soc. Canada*, **6**, 185.
(88*a*) Orbit (Zwiers) *Astrophysical Journal*, **21**, 178.
(105) Orbit (Lunt) *Astrophysical Journal*, **44**, 260; Orbit (Wilson) *Lick Obs. Bull.*, **9**, 117.
(117) *Astrophysical Journal*, **21**, 373.
(133) Visual orbit (Aitken) *Lick Obs. Bull.*, **2**, 55.
(157) *Astron. Nach.*, **147**, 92; *Astrophysical Journal*, **21**, 315, and **27**, 310.
(194) *Astron. Nach.*, **147**, 89.
(209) Orbit (Harper) *Jour. Roy. Astron. Soc., Canada*, **4**, 194.
(216, 217) Visual orbits and velocity ephemeris, etc. (Lunt) *Astrophysical Journal*, **48**, 182.
(247) Orbit (Halm) *Cape Annals*, **10**, 56C, and *Astrophysical Journal*, **44**, 250.
(257) Orbit (Plummer) *Lick Obs. Bull.*, **5**, 24.
(303) Recorded as a binary, *Lick Obs. Bull.*, **7**, 125.
(314) Orbit (Merrill) *Lick Obs. Bull.*, **6**, 6.
(343) Orbit (Crawford) *Lick Obs. Bull.*, **1**, 29.

TABLE V

H.R. No.	Plate No.	Star and Date	Sid. Time and R.A.	Rad. Vel. km	O.−C. km
99	.....	α *Phoenicis*[a]	0^h21^m3	.....	
165	.....	δ *Andromedae*	0^h34^m0	.....	
	4664	1915 Dec. 2	2 4	− 9.6*	.....
	4853	1916 Nov. 23	1 20	−13.8*	.....
	4854	Nov. 24	1 7	− 9.0*	.....
566	.....	χ *Eridani*[b]	1^h52^m0	.....	
	2060	1908 Dec. 4	2 53	− 6.4	.....
	2597	1909 Dec. 7	2 55	− 5.8	.....
	3356	1911 Nov. 16	1 3	− 2.2	.....
	3400	Dec. 19	3 48	− 6.1	.....
	3907	1912 Nov. 27	2 46	− 9.9	.....
	3907	Nov. 27	.....	−10.4*	.....
1366	.....	α *Reticuli*[c]	4^h13^m1	.....	
	2612	1910 Jan. 10	4 54	+33.3	.....
	3344	1911 Nov. 7	1 50	+37.0	.....
	3361	Nov. 26	5 55	+36.2	.....
	3432	1912 Jan. 24	5 39	+39.6	.....
	3897	Nov. 15	2 9	+35.2	.....
	3897	Nov. 15	2 9	+34.9*	.....
1543	.....	π^3 *Orionis*[d]	4^h44^m4	.....	
	1966	1908 Oct. 21	4 10	+24.3	.....
	2109	1909 Jan. 9	5 20	+26.2	.....
	2176	Jan. 28	5 47	+24.6	.....
	2857	1910 Nov. 4	5 4	+22.6	.....
	3277	1911 Sept. 13	3 48	+19.6	.....
	3289	Oct. 2	3 54	+21.1	.....
2061	.....	α *Orionis*[e]	5^h49^m8	.....	
2421	.....	γ *Geminorum*[f]	6^h31^m9	.....	
	4483	1915 Jan. 26	7 6	−17.0	.....
	4715	1916 Mar. 3	6 45	+ 3.3*	.....
	4717	Mar. 4	6 36	+ 5.1*	.....
2473	.....	ε *Geminorum*[g]	6^h37^m8	.....	
	2293	1909 Mar. 26	8 7	+ 7.5	.....
	4702	1916 Feb. 18	6 59	+12.9*	.....
	4706	Feb. 23	7 23	+13.6*	.....
2491	.....	α *Canis Majoris*[h] ...	6^h40^m7	.....	
	1956	1908 Oct. 13	5 10	− 9.0	−1.5
	2230	1909 Feb. 16	6 39	− 8.2	−0.6
	2325	Apr. 17	10 11	− 8.2	−0.6
	2330	Apr. 22	9 42	− 8.6	−1.0
	3501	1912 Feb. 26	6 28	− 8.2	−0.2
	3502	Feb. 26	6 45	− 9.1	−1.1
	3529	Mar. 11	7 4	− 7.0	+1.0
	3535	Mar. 15	7 7	− 7.2	+0.8
	3539	Mar. 16	6 49	− 8.5	−0.5
2553	.....	τ *Puppis*	6^h47^m5	.....	
	2015	1908 Nov. 16	6 0	+34.3	.....
	2231	1909 Feb. 16	7 50	+32.8	.....
	2263	Mar. 3	7 11	+29.7	.....
	2953	1911 Jan. 18	7 54	+31.9	.....
	3018	Feb. 21	8 28	+34.5	.....
	3326	Oct. 26	4 35	+34.5†	.....
	3865	1912 Oct. 23	5 40	+42.3	.....
	4256	1914 Mar. 14	7 23	+33.1	.....
2693	.....	δ *Canis Majoris*	$7^h\ 4^m3$	.....	
	1937	1908 Oct. 7	4 12	+32.2	.....
	2089	Dec. 18	8 6	+32.0	.....
	2196	1909 Feb. 3	6 50	+31.2	.....
	2237	Feb. 19	8 3	+34.1 †	.....
	2252	Feb. 27	8 34	+32.8	.....
	2283	Mar. 19	7 46	+32.9	.....
	2854	1910 Oct. 25	6 38	+34.5	.....

	2869	1910 Nov. 13	6 14	+33.3		3185	4186	1913 Dec. 29	9 59	+46.5	
	2917	Dec. 13	7 15	+33.4			4747	1916 Apr. 14	11 14	+44.0*	
	2986	1911 Feb. 6	7 32	+33.3		3445	.....	*b Velorum*	8^h37^m3	.....	
2736	.....	*γ^2 Volantis*	7^h9^m6	.....			4286	1914 Apr. 17	10 2	+21.6	
	3086	1911 Apr. 1	8 56	+ 0.9			4555	1915 May 3	10 30	+20.3*	
	3403	Dec. 22	7 53	+ 2.6			4557	May 4	10 16	+23.6*	
	3563	1912 Mar. 28	8 32	+ 2.3		3482	.....	*ϵ Hydrae*	8^h41^m5	.....	
	4692	1916 Jan. 27	5 55	+ 6.6			2318	1909 Apr. 15	9 22	+38.6	
2878	.....	*σ Puppis*[l]	7^h26^m1	.....			2333	Apr. 26	9 59	+38.6	
3045	.....	*ξ Puppis*[l]	7^h45^m1	.....			4734	1916 Mar. 29	9 24	+31.8*	
	2104	1909 Jan. 5	8 52	+ 2.3		4057	.....	*γ Leonis*	10^h14^m5	.....	
	2126	Jan. 15	5 52	+ 0.2			2046	1908 Nov. 30	7 30	−38.1	
	3418	1912 Jan. 18	5 11	+ 3.4			2066	Dec. 6	8 46	−35.7	
	3454	Feb. 6	7 7	+ 4.2			2340	1909 May 4	10 45	−36.0	
	3460	Feb. 8	6 22	+ 8.4			2933	1910 Dec. 23	8 4	−36.9	
	3471	Feb. 12	8 51	+ 3.8		4450	.....	*ξ Hydrae*[k]	11^h28^m1	.....	
3080	.....	*a Puppis*	7^h48^m8	.....			2246	1909 Feb. 25	13 6	− 9.4	
	3103	1911 Apr. 15	8 53	+28.2			3150	1911 May 23	13 12	− 3.5	
	3560	1912 Mar. 27	9 32	+15.5			3633	1912 May 30	12 50	− 1.3	
	4553	1915 Apr. 20	10 9	+31.5		4825–6	.....	*γ Virginis*	12^h36^m6	.....	
	4745	1916 Apr. 13	9 40	+31.8			4556 Np	1915 May 3	12 22	−17.2	
	4749	Apr. 17	9 11	+31.2	*		4567 Sf	May 25	13 33	−19.3	*
	4760	May 2	9 16	+30.9			4569 Sf	June 3	12 32	−19.3	
	4761	May 3	10 5	+33.0		5235	.....	*η Boötis*[l]	13^h49^m9	.....	
3185	.....	*ρ Puppis (ι Argus)*	8^h3^m3	.....			2157	1909 Jan. 22	12 22	+ 1.9	
	2090	1908 Dec. 18	8 52	+45.9			2214	Feb. 10	12 9	+ 4.0	
	2127	1909 Jan. 15	8 47	+49.9	†		2421	July 17	13 50	− 4.2	
	2179	Jan. 29	9 20	+47.4			3039	1911 Mar. 3	13 6	− 7.4	
	2281	Mar. 16	9 26	+46.2			3200	June 27	13 38	+ 7.0	
	3382	1911 Dec. 8	7 1	+49.1			3634	1912 May 30	14 46	− 5.2	
	3420	1912 Jan. 19	6 20	+49.0			3683	July 2	14 17	− 3.9‡	
	3441	Jan. 29	6 25	+48.4			3714	July 16	15 24	− 3.7‡	

* Measures by Halm.

† Mean of measures by Halm and Lunt.

‡ Wide slit.

a See *Astrophysical Journal*, **47**, 196.

b *Lick Obs. Bull.* **7**, 117, gives −5.7

c *Lick Obs. Bull.* **7**, 117, gives +35.4.

d *Lick Obs. Bull.* **7**, 114, gives +25.0.

e See *Astrophysical Journal*, **44**, 250.

f Velocities do not fit Harper's orbit.

g *Lick Obs. Bull.*, **7**, 118, gives +9.6.

h Computed values from Campbell's formula, *Astrophysical Journal*, **21**, 181.

i See *Astrophysical Journal*, **44**, 260, and *Lick Obs. Bull.* **9**, 117.

j *Lick Obs. Bull.*, **7**, 118, gives +4.2.

k *Lick Obs. Bull.*, **7**, 118, gives −4.4.

l Cape, Bonn, and Chile results show large residuals from Harper's orbit.

TABLE V—*Continued*

H.R. No.	Plate No.	Star and Date	Sid. Time and R.A.	Rad. Vel. km	O.−C. km	H.R. No.	Plate No.	Star and Date	Sid. Time and R.A.	Rad. Vel. km	O.−C. km
5459	.....	α_1 *Centauri*[a]	14^h32^m8	.....		6746	3524	1912 Mar. 6	.....	+22.0	.....
5460	.....	α_2 *Centauri*[a]	14^h32^m8	.....			3575	Apr. 10	.....	+21.2	.....
6056	.....	δ *Ophiuchi*[b]	$16^h\ 9^m1$	.....			3577	Apr. 11	.....	+22.2	.....
	1790	1908 July 31	.....	−25.3*‡	.....		3582	Apr. 14	.....	+21.3	.....
	1791	July 31	.....	−25.3	.....		3585	Apr. 15	.....	+23.2	.....
	2799	Aug. 10	.....	−24.7	.....		3587	Apr. 16	.....	+20.9	.....
	3108	1911 Apr. 21	.....	−14.8	.....		3594	Apr. 18	.....	+21.5	.....
	3177	June 15	.....	−18.1	.....		3786	Aug. 31	.....	+21.2	.....
6134	.....	α *Scorpii*[c]	16^h23^m3	.....			3832	Oct. 4	.....	+21.8	.....
6148	.....	β *Herculis*[d]	16^h25^m9	.....			3852	Oct. 16	.....	+21.9	.....
	2337	1909 May 3	.....	−26.4	+2.4	6869	.....	η *Serpentis*[f]	18^h16^m1	.....	
	3719	1912 July 18	.....	− 5.7	+1.0		2321	1909 Apr. 15	.....	+16.9	.....
	4786	1916 June 16	.....	−33.0*	−1.9		2465	Aug. 26	.....	+ 5.0	.....
6561	.....	ξ *Serpentis*	17^h31^m9	.....			2476	Sept. 2	.....	+ 4.8	.....
	4091	1913 July 29	.....	−30.1	.....		2841	1910 Oct. 7	.....	+ 1.8	.....
	4807	1916 Aug. 21	.....	−41.3*	.....		3250	1911 Aug. 19	.....	+ 6.2	.....
	4808	Aug. 21	.....	−43.5*	.....		4103	1913 Aug. 13	.....	+ 6.1	.....
6615	.....	ι' *Scorpii*[e]	17^h40^m6	.....	.....	7234	.....	τ *Sagittarii*	19^h0^m7	.....	
	2289	1909 Mar. 22	.....	−27.4†	.....		1939	1908 Oct. 8	.....	+52.2	.....
	2485	Sept. 4	.....	−30.7	.....		2493	1909 Sept. 8	.....	+50.0	.....
	2492	Sept. 8	.....	−31.7	.....		2523	Oct. 2	.....	+51.4	.....
	3109	1911 Apr. 21	.....	−25.6	.....		2525	Oct. 7	.....	+49.5	.....
6746	.....	γ *Sagittarii*	17^h59^m4	.....	.....		3822	1912 Sept. 26	.....	+40.6	.....
	2506	1909 Sept. 17	.....	+24.1	.....		3831	Oct. 1	.....	+43.4	.....
	2516	Sept. 25	.....	+19.6	.....	7417	.....	β *Cygni*	19^h26^m7	.....	
	3031	1911 Feb. 27	.....	+23.3	.....		4619	1915 Sept. 24	.....	−22.0 }	.....
	3037	Mar. 2	.....	+22.7	.....		4812	1916 Aug. 28	.....	−22.1 }*	.....
	3044	Mar. 9	.....	+22.7	.....		4813	Aug. 29	.....	−22.7 }	.....
	3074	Mar. 22	.....	+19.6	.....	7754	.....	α_2 *Capricorni*	20^h12^m5	.....	
	3281	Sept. 29	.....	+20.5	.....		1957	1908 Oct. 15	.....	+ 0.7	.....
	3288	Sept. 30	.....	+20.4	.....		2544	1909 Oct. 21	.....	− 8.0	.....
	3312	Oct. 20	.....	+22.6	.....		4620	1915 Sept. 28	.....	+ 0.8*	.....

7776	.....	*β Capricorni*[g]	20^h15^m4	.....	.....	8204	.....	*ζ Capricorni*	21^h21^m0	.....	.....
	1930	1908 Oct. 6	.....	− 7.4	.....		1976	1908 Oct. 29	.....	+ 4.3	.....
	1934	Oct. 7	.....	− 7.7	−0.2		1980	Oct. 30	.....	+ 4.5	.....
	1943	Oct. 9	.....	− 8.5			2011	Nov. 14	.....	+ 3.3	.....
	1963	Oct. 18	.....	− 8.2†	−0.9	8278	.....	*γ Capricorni*	21^h34^m6	.....	.....
	2335	1909 Apr. 29	.....	− 2.4	+0.3		1971	1908 Oct. 22	.....	−34.2†	.....
	2354	May 16	.....	− 2.1	+0.4		1989	Nov. 4	.....	−31.1†	.....
	2482	Sept. 3	.....	− 3.9	+0.2		3828	1912 Sept. 30	.....	−29.0	.....
	2490	Sept. 7	.....	− 1.0		8502	.....	*α Toucani*	22^h11^m7	.....	.....
	2517	Sept. 25	.....	− 4.6	† −0.1		1960	1908 Oct. 16	.....	+49.7	.....
	2554	Oct. 30	.....	− 3.2			2823	1910 Sept. 20	.....	+42.4	.....
	2844	1910 Oct. 14	.....	−43.4	−0.9		2847	Oct. 21	.....	+41.6	.....
	2846	Oct. 21	.....	−41.3			3224	1911 July 16	.....	+36.5	.....
	3153	1911 May 26	.....	−25.2	0.0		3232	July 26	.....	+36.7	.....
	3182	June 16	.....	−24.3	−0.3		3292	Oct. 3	.....	+37.4	.....
	3191	June 22	.....	−25.6	−1.9		3343	Nov. 7	.....	+36.2	.....
	3291	Oct. 3	.....	−19.7	−1.2		3702	1912 July 9	.....	+38.2	.....
	3823	1912 Sept. 26	.....	− 4.8	+0.8	8650	.....	*η Pegasi*	22^h38^m3	.....	.....
7882	.....	*β Delphini*	20^h32^m9	.....	.....		4642	1915 Oct. 30	.....	+ 5.3	* .....
	4630	1915 Oct. 18	.....	−21.6	.....		4840	1916 Oct. 26	.....	+ 6.7	.....
	4821	1916 Sept. 15	.....	−22.1	*		4842	Oct. 27	.....	+ 9.0	.....
	4825	Sept. 22	.....	−30.7	.....	8775	.....	*β Pegasi*[h]	22^h58^m9	.....	.....
8115	.....	*ζ Cygni*	21^h8^m7	.....	.....		4143	1913 Oct. 13	.....	− 1.9	.....
	4834	1916 Oct. 9	.....	+20.0	.....		4432	1914 Oct. 26	.....	− 1.3	.....
	4835	Oct. 12	.....	+20.4	*		4444	Nov. 13	.....	+ 4.2	.....
	4836	Oct. 13	.....	+20.0	.....						
	4837	Oct. 16	.....	+21.7	.....						

* Measures by Halm.

† Mean of measures by Halm and Lunt.

‡ Wide slit.

a See *Astrophysical Journal*, **48**, 182.

b *Lick Obs. Bull.*, **7**, 127, gives −19.5; Adams gives −17.5.

c See *Astrophysical Journal*, **44**, 257.

d Computed values from Plummer's orbit, *Lick Obs. Bull.*, **5**, 25.

e *Lick Obs. Bull.* **7**, 116, gives −27.8.

f *Lick Obs. Bull.*, **7**, 125, gives +9.5; Bonn gives +11.1 to +8.3.

g Computed values from Merrill's orbit, *Lick Obs. Bull.*, **6**, 6.

h *Lick Obs. Bull.*, **7**, 128, gives +8.4; Adams gives +10.6.

TABLE VI

Cape List No.	H. R. No.	Star	α 1900	δ 1900	Mag.	Type	Rad. Vel. (Lick)
18.....	553	β Arietis*.....	1 49.1	+20 19	2.72	A5	− 1.
22.....	591	α Hydri†.....	55.6	−62 3	3.02	F	− 5.
54.....	1412	θ^2 Tauri*.....	4 22.9	+15 39	3.62	A5	.....
65.....	1666	β Eridani†.....	5 2.9	− 5 13	2.92	A2	− 8.
72.....	1998	ζ Leporis†.....	42.4	−14 52	3.67	A2	.....
88.....	2484	ξ Geminorum*...	6 39.7	+13 0	3.40	F5	+27.
89.....	2540	θ Geminorum‡...	46.2	+34 5	3.64	A2	+ 8.
90.....	2550	α Pictoris§†.....	47.2	−61 50	3.30	A5	.....
100.....	2763	λ Geminorum*...	7 12.3	+16 43	3.65	A2	− 9.
102.....	2777	δ Geminorum*...	14.2	+22 10	3.51	F	.....
144.....	3786	ψ Velorum*.....	9 26.8	−40 2	3.64	F5	.....
155.....	4031	ζ Leonis*.....	10 11.1	+23 55	3.65	F	.....
174.....	4357	δ Leonis†.....	11 8.8	+21 4	2.58	A2	−18.
181.....	4534	β Leonis*.....	44.0	+15 8	2.23	A2	+ 1.3
202.....	5028	ι Centauri*§....	13 15.0	−36 11	2.91	A2	+ 2.0
205.....	5107	ζ Virginis†.....	29.6	− 0 5	3.44	A2	.....
222.....	5531	α^2 Libra*.....	14 45.3	−15 38	2.90	A2	.....
237.....	5897	β Triang. Aust.*.	15 46.3	−63 7	3.04	F	.....
248.....	6095	γ Herculis*.....	16 17.5	+19 23	3.79	F	−39.
258.....	6380	η Scorpii*.....	17 5.0	−43 6	3.44	F2	−28.
260.....	6445	ξ Ophiuchi*.....	15.0	−21 1	4.46	F5	− 8.6
266.....	6553	θ Scorpii*.....	30.1	−42 56	2.04	F	+ 5.
267.....	6556	α Ophiuchi†.....	30.3	+12 38	2.14	A5	.....
292.....	7194	ζ Sagittarii¶.....	18 56.3	−30 1	2.71	A2	+22.
302.....	7377	δ Aquilae*.....	19 20.5	+ 2 55	3.44	F	.....
306.....	7557	α Aquilae†.....	45.9	+ 8 36	0.89	A5	−33.
317.....	7913	β Pavonis*.....	20 36.0	−66 34	3.60	A5	+ 9.4
332.....	8322	δ Capricorni*....	21 41.5	−16 35	2.98	A5	.....
339.....	8558–9	ζ Aquarii(du)*...	22 23.7	− 0 32	3.81	F5	+27.1
346.....	8675	ε Gruis†.....	42.5	−51 51	3.69	A2	.....
350.....	8709	δ Aquarii†.....	49.3	−16 21	3.51	A2	+22.
352.....	8728	α Piscis Aust.†...	52.1	−30 9	1.29	A3	+ 6.7
355.....	8787	θ Gruis*.....	23 1.2	−44 4	4.35	F5	+10.0

* Faint diffuse lines.
† Hα and Hδ (Mg 4481).
‡ Not observed.
§ Type stars.
¶ Plate missing.

The results for individual stars are given in Table II. They may be divided as follows:

	km	km	
Chile *minus* Cape	0.0 to	0.5	18 stars
	0.6 to	1.0	6
	1.1 to	1.5	3
	1.6 to	2.0	4
	2.1 to	2.3	2
			33 stars

The mean range for Chile is 1.9 km and for the Cape 2.8 km, but the Cape results depend on 311 plates as compared with 147 plates taken in Chile.

Eleven of the stars have a range equal to or smaller than that shown by the Chile plates and 22 larger.

The 18 stars in Table I show a more consistent positive difference, viz., +0.6 km, Lick−Cape, when compared with Campbell's values in *Lick Observatory Bulletin*, No. 229.

In Table III 24 stars have also been observed at Bonn[1] by Küstner and Zurhellen. The greatest difference in velocity is −1.7 km Bonn−Cape in the case of η Piscium, a star suspected to be variable by Lord and Maag.[2] The Cape and Lick velocities agree. Only 5 stars show a difference over a kilometer. The Bonn velocities were corrected −1.0 km in accordance with the observations made on the isolated peaks near the terminator of the moon. The mean difference Bonn−Cape is 0.14 km per sec.

Eleven stars could be compared with the results of Lord and Maag[3] at the Emerson McMillin Observatory at Columbus. These show a positive difference throughout amounting to +2.1 km in the mean. Their observations of Venus taken as a check indicate that their velocities are too high (positive) by 1.8 km, and if their results are corrected by this amount the difference Columbus−Cape becomes only +0.3 km.

We have therefore the following corrected

SYSTEMATIC DIFFERENCES

76 stars	Lick−Cape	+0.1 km	(Table III)
33	Chile−Cape	−0.3	(Table II)
24	Bonn−Cape	+0.1	Correction applied −1.0 km
18	Lick−Cape	+0.6	(Table I)
11 stars	Columbus−Cape	+0.3	Correction applied −1.8 km

Mean results for each of the 76 stars considered as constant in velocity are given in Table III. Table IV gives the particulars relating to the 43 stars known or suspected to be spectroscopic binaries. It is self-explanatory. Table V gives the results of the

[1] *Astrophysical Journal*, **27**, 301, 1908. [2] *Ibid.*, **21**, 313, 1905. [3] *Ibid.*

measures of individual plates of the stars of Table IV. Thirty-three stars of the A and F types, which were included in the list for observation with a narrow slit, and which were found to have spectra unsuitable for inclusion in the present series either because of the faint and diffuse nature of the lines with the dispersion employed or the paucity of lines, are shown in Table VI.

These stars are not comparable with the type stars Sirius (A), Canopus (F), and α Can. Min. (F_5), which have much heavier and sharper absorption lines well suited for measurement of velocities.

Those stars marked † generally show only the hydrogen lines Hγ and Hδ and in some cases the Mg line at 4481 in the limited field of spectrum photographed. Those marked * show numerous hazy lines of feeble absorption. These stars are better dealt with by using a smaller dispersion.

Velocities for 20 of the stars in Table VI, in most cases approximate, have been published in *Lick Observatory Bulletin*, **7**, 20 and 114, and are inserted in the table.

ROYAL OBSERVATORY, CAPE OF GOOD HOPE
May 16, 1918

STUDIES BASED ON THE COLORS AND MAGNITUDES IN STELLAR CLUSTERS[1]

EIGHTH PAPER: THE LUMINOSITIES AND DISTANCES OF 139 CEPHEID VARIABLES

By HARLOW SHAPLEY

Aside from the error involved in the determination of the zero-point of the luminosity-period curve,[2] most of the error affecting the absolute parallax of an isolated Cepheid variable is due to the uncertainty of apparent magnitude, since the period of light-variation is usually known with an accuracy that for this work is superfluous. Scores of observers, employing numerous methods and systems of magnitudes, have participated in the discovery and observation of these stars; but observations have often been made solely for the determination of periods, little attention being given to light-curves or accurate values of maximum and minimum light. Frequently the magnitudes are referred to the system of the *Bonner Durchmusterung*, and only occasionally, for the brighter or best known stars, to the Potsdam or Harvard photometric scales.

Adding to the uncertainty in the systems of magnitude the occasional difficulty, arising from changes in the form of light-curves, in obtaining accurate mean values of maximum and minimum brightness, we must expect an average probable error in the adopted median magnitude of the order of 0.4 mag. The consequent average probable error computed for the parallaxes of stars that are normal Cepheids is about 20 per cent of the tabulated values; for a number of the brighter stars and for well-observed cluster-type variables the error is only a little more than half that amount, but possibly it attains a maximum of 50 per cent for some of the faintest stars that are scantily observed on uncertain magnitude systems. Accurate determinations of the apparent visual or

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 153.

[2] *Mt. Wilson Contr.*, No. 151, sec. III.

photovisual magnitude should reduce the probable error of the parallax of any Cepheid to less than 15 per cent.

The estimated range of 10 to 50 per cent in the probable error of the parallaxes allows for a variation in the probable error of apparent median brightness from a tenth to a whole magnitude—an amount which is shown by an examination of the underlying observational material to be sufficient. We note, therefore, that for parallaxes obtained with the period-luminosity curve the accuracy appears to surpass that of direct measures on any object for which the parallax is less than 0".01, and is essentially independent of distance. About two-thirds of the Cepheids now known have parallaxes smaller than 0".001.

The greatest chance for serious error in the work lies in the unintentional inclusion of some stars that are not typical Cepheids. For a star showing periodic continuous variation which simulates certain Cepheid characteristics but exhibits peculiarities such as double maxima or minima, we have found from cluster studies that the absolute brightness usually is less than for typical variables having the same period. The mean periods of such peculiar stars are often long; and, conversely, Cepheids of very long period are frequently abnormal. Until the normality of period and light-curve is established, we must, therefore, look with some doubt upon the enormously great absolute luminosity (and distance) obtained for galactic variables with periods in excess of forty days. Accordingly such stars are relegated to a supplementary table, which also contains provisional parallaxes and luminosities of variables that for various other reasons seem uncertain.

The list of variables in Table I is essentially complete for typical stars with definitely determined periods less than forty days. The various Harvard compilations and Hartwig's annual catalogue are the principal sources of observational data.[1] Names and posi-

[1] *Note added to proof, April, 1918.*—Hartwig's catalogue and ephemeris of variable stars for 1915 was the last number of that annual publication available when the tables for this paper were compiled. The issue for 1918, which has now been received, contains not only numerous revisions of the periods of the older variables but also some additions to the list. The corrections demanded by the revised periods have been applied to the values in all the tables, the text has been modified where necessary, and the statistical results in Tables II–VI now include the data for the twelve additional stars in Table I*a*.

tions have been taken, whenever possible, from Table VIII of *Harvard Annals*, **56**. For a majority of the stars the median visual magnitude of the eighth column is the mean of the maximum and minimum magnitudes given in this Harvard list, although for a number of variables improved magnitudes are obtainable from recent literature. All photographic magnitudes have been reduced to the visual system with the aid of a mean color-curve. The periods are mainly from Hartwig's catalogues, but occasionally recent publications afford better values. The parallaxes have been computed from the absolute magnitudes, which were read directly from the luminosity-period curve. A representation of the curve appears in Fig. 1 of *Contribution* No. 151. For the sake of uniformity the first decimal place is retained for all the distances in the last three columns, though for the larger values it is generally meaningless.

The 35 stars in Table II include: (1) all with periods greater than forty days, some of which, RS Puppis, for instance, seem to show typical Cepheid variation, although others, with M-type spectra, may be classed more correctly with the long-period variables; (2) a few with period or type somewhat uncertain; (3) 7 stars that appear to belong to the RV Tauri type of variation,[1] and (4) a number known to be otherwise peculiar or irregular. Further observation is sure to place some of these stars with those of Table I. While it is very probable that the absolute brightness of all of them is high, in many cases the luminosity-period relation may not hold rigorously. Moreover, the high galactic latitude of some variables with periods in excess of forty days suggests, as strongly as the frequent peculiarities of period and amplitude, that these stars differ too greatly from the typical Cepheid to make the estimated distances of much value.

[1] The periods of RV Tauri, R Sagittae, and V Vulpeculae are taken as thirty-nine, thirty-five, and thirty-eight days, respectively; these values, representing approximately the cycle of the principal variations, are more likely to give correct absolute luminosities. Cf. van der Bilt, *Recherches Astronomiques de l'Observatoire d'Utrecht*, VI, 1916. On the authority of Enebo similar treatment is accorded TV Andromedae, RY Lacertae, SW Persei, and RX Ursae Majoris. L_2 Puppis is a bright southern variable that may belong to this interesting type; a critical examination of its spectrum is very desirable. The study of the secondary variations of such typical stars as RR Lyrae (*Astrophysical Journal*, **43**, 217, 1916) shows that the difference between the RV Tauri type and the ordinary Cepheids is not so great as appears superficially.

TABLE I

PARALLAXES AND DISTRIBUTION IN SPACE OF 127 CEPHEID VARIABLES*

No.	Name	Position in 1900		Galactic		Period in Days	Med. Mag. Visual	Abs. Mag.	Parallax	Distance (Unit Is 100 Parsecs)		
		R.A.	Decl.	Long.	Lat.					Radial	Projected	From Plane
1...	SY Cassiopeiae	$0^h\ 9^m.8$	+57°52′	85°	− 4°	4.071	9.6	−1.8	0″.00052	19.2	19.2	− 1.3
2...	SW Andromedae	0 18.4	+28 51	85	−33	0.442	9.3	−0.3	0.0012	8.3	7.0	− 4.5
3...	TU Cassiopeiae	0 20.9	+50 44	88	−11	2.137	7.9	−1.2	0.0015	6.6	6.5	− 1.3
4...	*a* Ursae Minoris	1 25.4	+88 46	91	+26	3.968	2.12	−1.81	0.016	0.6	0.5	+ 0.3
5...	RR Ceti	1 27.0	+ 0 50	114	−59	0.553	8.6	−0.4	0.0016	6.3	3.2	− 5.4
6...	RW Cassiopeiae	1 30.7	+57 15	97	− 4	14.80	9.5	−3.8	0.00022	45.4	45.3	− 3.2
7...	U Trianguli	1 49.7	+33 17	106	−27	0.447	11.6	−0.3	0.00042	23.8	21.2	−10.8
8...	UX Persei	2 6.1	+57 37	102	− 4	4.6	10.6	−2.0	0.00030	33.3	33.2	− 2.3
9...	UY Persei	2 27.1	+58 26	104	− 2	5.5	9.6	−2.2	0.00044	22.7	22.7	− 0.8
10...	SU Cassiopeiae	2 43.0	+68 28	101	+ 9	1.950	5.9	−1.2	0.0038	2.6	2.6	+ 0.4
11...	TU Persei	3 1.8	+52 48	111	− 5	0.607	11.7	−0.4	0.00038	26.3	26.2	− 2.3
12...	RW Camelopardalis	3 46.2	+58 22	112	+ 5	16.402	8.8	−3.9	0.00029	34.5	34.4	+ 3.0
13...	SX Persei	4 10.2	+41 29	126	− 5	4.290	10.8	−1.9	0.00029	34.5	34.4	− 3.0
14...	SZ Tauri	4 31.4	+18 20	147	−17	3.149	7.1	−1.6	0.0018	5.5	5.2	− 1.6
15...	SV Persei	4 42.8	+42 7	130	0	11.128	8.9	−3.3	0.00036	27.8	27.8	0
16...	RX Eridani	4 45.2	−15 54	182	−33	0.587	9.2	−0.4	0.0012	8.2	6.9	− 4.5
17...	SU Aurigae	4 49.6	+30 24	140	− 7	0.470	8.7	−0.3	0.0016	6.3	6.2	− 0.8
18...	U Leporis	4 52.0	−21 23	188	−33	0.581	9.5	−0.4	0.0010	9.5	8.0	− 5.2
19...	RX Aurigae	4 54.5	+39 49	134	0	11.626	7.6	−3.4	0.00063	15.9	15.9	0
20...	SY Aurigae	5 5.5	+42 43	133	+ 4	10.138	9.2	−3.2	0.00033	30.3	30.2	+ 2.1
21...	Y Aurigae	5 21.5	+42 21	134	+ 6	3.859	9.6	−1.8	0.00052	19.2	19.1	+ 2.0
22...	RZ Geminorum	5 56.6	+22 15	155	+ 1	5.529	9.4	−2.2	0.00048	20.8	20.8	+ 0.4
23...	RS Orionis	6 16.5	+14 44	164	+ 2	7.566	8.6	−2.7	0.00055	18.2	18.2	+ 0.6
24...	T Monocerotis	6 19.8	+ 7 8	171	− 1	27.012	6.2	−4.7	0.00066	15.2	15.2	− 0.3
25...	RT Aurigae	6 22.1	+30 34	151	+11	3.728	5.3	−1.8	0.0038	2.6	2.6	+ 0.5
26...	RZ Camelopardalis	6 23.7	+67 6	115	+23	0.480	12.0	−0.3	0.00035	28.6	26.3	+11.2
27...	W Geminorum	6 29.2	+15 24	165	+ 5	7.916	7.1	−2.8	0.0010	9.5	9.5	+ 0.8
28...	ζ Geminorum	6 58.2	+20 43	164	+13	10.154	4.0	−3.2	0.0036	2.8	2.7	+ 0.6
29...	TZ Aurigae	7 4.6	+40 56	143	+23	0.392	11.8	−0.3	0.00038	26.3	24.2	+10.3
30...	RR Geminorum	7 15.1	+31 4	155	+21	0.397	10.2	−0.3	0.00079	12.7	11.9	+ 4.5

31...	X Puppis	7 28.4	−20 42	204	0	25.953	8.5	−4.6	0.00024	41.7	41.7	0	
32...	V Carinae	8 26.7	−59 47	242	−12	6.695	7.8	−2.5	0.00087	11.5	11.2	− 2.4	
33...	T Velorum	8 34.4	−47 1	233	− 3	4.639	8.0	−2.0	0.0010	10.0	10.0	− 0.5	
34...	V Velorum	9 19.2	−55 32	244	− 4	4.371	7.8	−1.9	0.0012	8.7	8.7	− 0.6	
35...	*l* Carinae	9 42.5	−62 3	251	− 7	35.523	4.3	−5.1	0.0013	7.6	7.5	− 0.9	
36...	RR Leonis	10 2.1	+24 29	176	+54	0.452	9.6	−0.3	0.0010	9.5	5.6	+ 7.7	
37...	UW Carinae	10 23.3	−59 10	254	− 1	5.346	9.0	−2.2	0.00058	17.2	17.2	− 0.3	
38...	YZ Carinae	10 24.6	−58 51	253	− 1	18.158	8.6	−4.1	0.00029	34.5	34.5	− 0.6	
39...	UX Carinae	10 25.4	−57 6	252	+ 1	3.682	8.2	−1.7	0.0010	9.5	9.5	+ 0.2	
40...	UY Carinae	10 28.5	−61 16	255	− 3	5.544	8.8	−2.2	0.00063	15.9	15.9	− 0.8	
41...	Y Carinae	10 29.4	−57 59	253	0	3.640	8.4	−1.7	0.00096	10.4	10.4	0	
42...	UZ Carinae	10 32.6	−60 30	255	− 2	5.205	9.3	−2.1	0.00052	19.2	19.2	− 0.7	
43...	SV Velorum	10 40.9	−55 46	253	+ 3	14.097	8.7	−3.7	0.00033	30.3	30.3	+ 1.6	
44...	VY Carinae	10 40.9	−57 2	254	+ 2	18.984	7.3	−4.1	0.00052	19.2	19.2	+ 0.7	
45...	WW Carinae	10 47.6	−58 51	256	0	4.676	9.6	−2.0	0.00048	20.8	20.8	0	
46...	WZ Carinae	10 51.4	−60 24	257	0	23.00	7.8	−4.4	0.00036	27.8	27.8	0	
47...	XX Carinae	10 53.4	−64 36	258	− 4	15.725	8.2	−3.8	0.00040	25.0	25.0	− 1.8	
48...	U Carinae	10 53.7	−59 12	256	0	38.740	7.4	−5.3	0.00029	34.5	34.5	0	
49...	XY Carinae	10 58.3	−63 43	258	− 3	12.434	8.9	−3.5	0.00033	30.3	30.3	− 1.6	
50...	XZ Carinae	11 0.1	−60 26	258	0	16.644	8.4	−3.9	0.00035	28.6	28.6	0	
51...	ST Centauri	11 5.5	−51 57	256	+ 8	3.151	10.0	−1.6	0.00048	20.8	20.6	+ 2.9	
52...	SU Draconis	11 32.2	+67 53	100	+49	0.660	9.2	−0.4	0.0012	8.3	5.4	+ 6.3	
53...	UZ Centauri	11 36.3	−62 8	262	0	3.334	9.2	−1.6	0.00069	14.5	14.5	0	
54...	S Muscae	12 7.4	−69 36	266	− 7	9.657	6.8	−3.1	0.0010	9.5	9.4	− 1.2	
55...	SW Draconis	12 12.8	+70 4	94	+48	0.570	10.0	−0.4	0.00083	12.0	8.0	+ 8.9	
56...	SX Centauri	12 15.9	−48 39	266	+14	16.50	8.2	−3.9	0.00038	26.3	25.5	+ 6.4	
57...	T Crucis	12 15.9	−61 44	267	+ 1	6.732	7.2	−2.5	0.0012	8.7	8.7	+ 0.2	
58...	R Crucis	12 18.1	−61 4	267	+ 1	5.825	7.3	−2.3	0.0012	8.3	8.3	+ 0.1	
59...	R Muscae	12 36.0	−68 52	270	− 7	0.882	7.0	−0.6	0.0030	3.3	3.3	− 0.4	
60...	Z Canum Venat.	12 45.0	+44 19	88	+73	1.890	10.2	−1.1	0.00055	18.2	5.3	+17.4	
61...	SS Hydrae	13 25.0	−23 8	284	+38	8.20	7.8	−2.8	0.00076	13.2	10.4	+ 8.1	
62...	VW Centauri	13 27.1	−63 33	275	− 2	15.037	8.9	−3.8	0.00029	34.5	34.5	− 1.2	
63...	RV Ursae Majoris	13 29.4	+54 31	74	+62	0.468	9.8	−0.3	0.00096	10.4	4.9	+ 9.2	
64...	ST Virginis	14 22.4	− 0 26	315	+53	0.411	10.8	−0.3	0.00060	16.7	10.0	+13.3	
65...	V Centauri	14 25.4	−56 27	284	+ 3	5.494	7.1	−2.2	0.0014	7.2	7.2	+ 0.4	
66...	RS Boötis	14 29.2	+32 11	18	+66	0.377	10.3	−0.3	0.00076	13.2	5.3	+12.0	

* Table Ia, which is appended to this table, contains twelve additional Cepheids. Cf. n. 1, p. 2.

TABLE I—*Continued*

No.	Name	Position in 1900		Galactic		Period in Days	Med. Mag. Visual	Abs. Mag.	Parallax	Distance (Unit Is 100 Parsecs)		
		R.A.	Decl.	Long.	Lat.					Radial	Projected	From Plane
67...	RU Boötis	14^h41^m5	+23°44′	358°	+63°	0.493	13.5	−0.3	0.″00017	58.8	26.7	+52.4
68...	RY Boötis	14 45.2	+23 27	356	+62	9.0	7.2	−3.0	0.00091	11.0	5.2	+ 9.7
69...	R Trianguli Aust.	15 10.8	−66 8	285	− 9	3.389	7.0	−1.7	0.0018	5.5	5.4	− 0.9
70...	U Normae	15 34.6	−54 59	293	− 1	12.641	8.9	−3.5	0.00033	30.3	30.3	− 0.5
71...	S Trianguli Aust.	15 52.2	−63 30	290	− 9	6.323	6.9	−2.4	0.0014	7.2	7.1	− 1.1
72...	U Trianguli Aust.	15 58.4	−62 38	291	− 9	2.568	8.1	−1.4	0.0013	7.9	7.8	− 1.2
73...	RW Draconis	16 33.8	+58 1	54	+40	0.443	10.4	−0.3	0.00072	13.9	10.6	+ 8.9
74...	RV Scorpii	16 51.8	−33 27	319	+ 4	6.062	7.1	−2.4	0.0013	7.9	7.9	+ 0.6
75...	SW Herculis	16 54.2	+21 42	9	+33	0.493	13.5	−0.3	0.00017	58.8	49.3	+32.0
76...	ST Ophiuchi	17 28.8	− 1 0	350	+15	0.450	11.6	−0.3	0.00042	23.8	23.0	+ 6.2
77...	X Sagittarii	17 41.3	−27 48	329	− 1	7.012	4.7	−2.6	0.0035	2.9	2.9	− 0.0
78...	RY Scorpii	17 44.3	−33 40	324	− 4	20.32	8.2	−4.2	0.00033	30.3	30.2	− 2.1
79...	Y Ophiuchi	17 47.3	− 6 7	347	+ 8	17.121	6.3	−4.0	0.00087	11.5	11.4	+ 1.6
80...	S Arae	17 51.4	−49 25	311	−13	0.452	9.3	−0.3	0.0012	8.3	8.1	− 1.9
81...	W Sagittarii	17 58.6	−29 35	330	− 5	7.595	4.7	−2.7	0.0033	3.0	3.0	− 0.3
82...	W Serpentis	18 4.1	−15 34	342	+ 2	14.153	9.0	−3.7	0.00029	34.5	34.5	+ 1.2
83...	WZ Sagittarii	18 11.1	−19 6	340	− 2	21.7	8.4	−4.4	0.00028	35.7	35.7	− 1.2
84...	Y Sagittarii	18 15.5	−18 54	340	− 4	5.773	5.8	−2.3	0.0024	4.2	4.2	− 0.3
85...	XX Sagittarii	18 19.0	−16 51	343	− 4	6.43	9.0	−2.7	0.00046	21.7	21.7	− 1.5
86...	U Sagittarii	18 26.0	−19 12	341	− 6	6.745	6.9	−2.5	0.0013	7.6	7.6	− 0.8
87...	Y Scuti	18 32.6	− 8 27	351	− 3	10.347	9.0	−3.2	0.00036	27.8	27.8	− 1.4
88...	Y Lyrae	18 34.2	+43 52	40	+20	0.503	11.8	−0.3	0.00038	26.3	24.7	+ 9.0
89...	RU Scuti	18 36.7	− 4 13	356	− 1	19.7	8.9	−4.2	0.00024	41.7	41.7	− 0.7
90...	RZ Lyrae	18 39.9	+32 41	29	+15	0.511	10.4	−0.3	0.00072	13.9	13.4	+ 3.6
91...	YZ Sagittarii	18 43.7	−16 50	346	− 8	9.553	7.4	−3.1	0.00079	12.7	12.6	− 1.8
92...	RT Scuti	18 44.0	−10 30	351	− 5	0.496	9.4	−0.3	0.0012	8.7	8.7	− 0.8
93...	SZ Aquilae	18 59.6	+ 1 9	3	− 3	17.136	8.7	−4.0	0.00029	34.5	34.5	− 1.8
94...	TT Aquilae	19 3.2	+ 1 9	4	− 5	13.753	7.6	−3.6	0.00058	17.2	17.1	− 1.5
95...	RR Lyrae	19 22.3	+42 36	43	+12	0.567	7.25	−0.35	0.0030	3.3	3.2	+ 0.7
96...	U Aquilae	19 24.0	− 7 15	359	−13	7.024	6.6	−2.6	0.0014	6.9	6.7	− 1.6
97...	XZ Cygni	19 30.4	+56 10	56	+16	0.467	9.7	−0.3	0.0010	10.0	9.6	+ 2.8

98...	U Vulpeculae	19 32.3	+20 7	24	− 2	7.990	7.0	−2.8	0.0011	9.1	9.1	− 0.3
99...	SU Cygni	19 40.8	+29 1	32	+ 2	3.846	6.6	−1.8	0.0021	4.8	4.8	+ 0.2
100...	η Aquilae	19 47.4	+ 0 45	8	−14	7.176	4.05	−2.62	0.0046	2.2	2.1	− 0.5
101...	S Sagittae	19 51.5	+16 22	23	− 7	8.382	5.8	−2.9	0.0018	5.5	5.5	− 0.7
102...	X Vulpeculae	19 53.3	+26 17	32	− 3	6.319	8.8	−2.4	0.00058	17.2	17.2	− 0.9
103...	XX Cygni	20 1.3	+58 40	60	+13	0.135	11.8	−0.4	0.00036	27.8	27.0	+ 6.2
104...	RW Aquilae	20 7.3	+15 46	24	−11	7.87	8.8	−2.8	0.00048	20.8	20.4	− 4.0
105...	SZ Cygni	20 29.6	+46 16	52	+ 3	15.113	9.2	−3.8	0.00025	40.0	40.0	+ 2.1
106...	X Cygni	20 39.5	+35 14	44	− 5	16.385	6.5	−3.9	0.00083	12.0	12.0	− 1.0
107...	T Vulpeculae	20 47.2	+27 52	40	−11	4.436	5.8	−2.0	0.0028	3.6	3.5	− 0.7
108...	UY Cygni	20 52.3	+30 3	43	−10	0.561	10.0	−0.4	0.00083	12.0	11.8	− 2.1
109...	VX Cygni	20 53.6	+39 48	50	− 5	20.125	9.7	−4.2	0.00017	58.8	58.6	− 5.1
110...	RV Capricorni	20 55.9	−15 37	1	−37	0.468	10.0	−0.3	0.00087	11.5	9.2	− 6.9
111...	TX Cygni	20 56.4	+42 12	52	− 3	14.726	9.1	−3.7	0.00028	35.7	35.7	− 1.9
112...	VY Cygni	21 0.4	+39 34	51	− 5	7.859	9.1	−2.8	0.00042	23.8	23.7	− 2.1
113...	SW Aquarii	21 10.2	− 0 20	20	−33	0.459	10.4	−0.3	0.00072	13.9	11.7	− 7.6
114*..	β Cephei	21 27.4	+70 7	75	+14	0.190	3.3	−0.4	0.018	0.6	0.5	+ 0.1
115...	VZ Cygni	21 47.7	+42 40	59	− 9	4.864	8.8	−2.0	0.00069	14.5	14.3	− 2.3
116...	Y Lacertae	22 5.2	+50 33	66	− 5	4.325	9.0	−1.9	0.00066	15.2	15.1	− 1.3
117...	δ Cephei	22 25.4	+57 54	73	+ 1	5.366	4.14	−2.19	0.0054	1.8	1.8	0
118...	Z Lacertae	22 36.9	+56 19	73	− 1	10.89	8.9	−3.3	0.00036	27.8	27.8	− 0.5
119...	RR Lacertae	22 37.4	+55 55	73	− 2	6.412	9.0	−2.4	0.00052	19.2	19.2	− 0.7
120...	V Lacertae	22 44.6	+55 48	74	− 3	4.983	9.0	−2.1	0.00060	16.7	16.7	− 0.9
121...	SW Cassiopeiae	23 2.9	+58 1	77	− 1	5.44	9.4	−2.2	0.00048	20.8	20.8	− 0.4
122...	RS Cassiopeiae	23 32.6	+61 53	82	+ 1	6.295	9.6	−2.4	0.00040	25.0	25.0	+ 0.4
123...	UU Cassiopeiae	23 45.8	+60 21	83	− 2	4.314	9.6	−1.9	0.00050	20.0	20.0	− 0.7
124...	RY Cassiopeiae	23 47.1	+58 12	83	− 2	12.328	9.8	−3.5	0.00022	45.4	45.4	− 1.6
125...	VW Andromedae	23 59.6	+34 12	80	−28	0.517	10.3	−0.3	0.00076	13.2	11.7	− 6.2
126†..	—Hydrae	12 25.2	−25 30	266	+37	0.479	10.9	−0.3	0.00057	17.5	14.0	+10.5
127†..	—Herculis	16 26.2	+18 36	3	+37	0.365	10.4	−0.3	0.00072	13.9	11.1	+ 8.4

* The possible uncertainty in the length of period suspected by Guthnick (*Astronomische Nachrichten*, **196**, 357, 1913; **205**, 97, 1917) does not affect the adopted absolute magnitude appreciably.

† These stars were added to the tables after receiving (February 1, 1918) the list of new variables in *Harvard Circular* No. 201.

TABLE Ia

ADDITIONS TO TABLE I

No.	Name	Galactic		Period in Days	Med. Mag. Visual	Parallax	Distance (Unit Is 100 Parsecs)		
		Long.	Lat.				Radial	Projected	From Plane
128	169. 1907 Leonis	149°	+55°	0.685	12.0	0.″00033	30.3	17.4	+24.8
129	RR Canum Venaticorum	110	+82	0.558	11.0	0.00052	19.2	2.7	+19.0
130	S Comae	181	+88	0.587	10.9	0.00055	18.2	0.6	+18.2
131	SX Ursae Majoris	77	+60	0.307	10.8	0.00060	16.7	8.4	+14.5
132	RU Canum Venaticorum	20	+73	0.364	11.1	0.00052	19.2	5.6	+18.4
133	W Canum Venaticorum	37	+70	0.552	10.3	0.00072	13.9	4.8	+13.1
134	172. 1907 Boötis	28	+66	0.622	10.8	0.00058	17.2	7.0	+15.7
135	X Scuti	346	− 3	4.187	9.8	0.00046	21.7	21.7	− 1.1
136	Z Scuti	355	− 2	12.9	9.2	0.00029	34.5	34.5	− 1.2
137	SX Aquarii	26	−35	0.536	11.8	0.00036	27.8	22.8	−15.9
138	VV Pegasi	46	−32	0.488	11.2	0.00050	20.0	17.0	−10.6
139	RZ Cephei	77	+ 6	0.309	9.4	0.0012	8.7	8.6	+ 0.9

The period of any star in Table II may be found, if desired, by reading its logarithm from the luminosity-period curve for the corresponding tabulated absolute magnitude; and the adopted median apparent magnitude can be readily computed from the parallax and absolute magnitude. The last five stars of the table were added from Hartwig's 1918 catalogue; see note 1, p. 280. The variables of Table II are not used in the diagrams or in the following discussion.

TABLE II

SUPPLEMENTARY LIST OF VARIABLES

No.	Name	Absolute Magnitude	Parallax
1.....	RX Andromedae	−5.5	0".00010
2.....	SZ Cassiopeiae	−5.6	0.00008
3.....	SW Persei	−6.5	0.00008
4.....	SW Aurigae	−4.7	0.00004
5.....	RV Tauri	−5.3	0.00009
6.....	SS Geminorum	−5.5	0.00018
7.....	V Lyncis	−6.2	0.00009
8.....	RU Camelopardalis	−4.4	0.00019
9.....	RS Puppis	−5.3	0.00029
10.....	Z Cancri	−6.2	0.00010
11.....	RX Ursae Majoris	−6.0	0.00003
12.....	S Antliae	−0.3	0.0042
13.....	Z Leonis	−5.8	0.00012
14.....	S Crucis	−2.0	0.0016
15.....	W Virginis	−4.0	0.00014
16.....	V Ursae Minoris	−6.2	0.00015
17.....	UV Draconis	−6.3	0.00010
18.....	TX Scorpii	−0.6	0.0021
19.....	κ Pavonis	−3.0	0.0032
20.....	S Vulpeculae	−6.1	0.00009
21.....	TX Aquilae	−5.1	0.00010
22.....	R Sagittae	−5.1	0.00013
23.....	V Vulpeculae	−5.2	0.00017
24.....	TW Pegasi	−6.3	0.00018
25.....	RY Pegasi	−4.6	0.00010
26.....	RY Lacertae	−6.0	0.00003
27.....	W Cephei	−2.4	0.00091
28.....	X Lacertae	−2.2	0.00076
29.....	TV Andromedae	−6.0	0.00007
30.....	RU Aquarii	−6.1	0.00009
31.....	TZ Persei	−4.0	0.00004
32.....	U Monocerotis	−5.5	0.00044
33.....	UU Herculis	−6.0	0.00010
34.....	TX Ophiuchi	−6.2	0.00005
35.....	AP Sagittarii	−3.3	0.00083

There can be no doubt of the intimate relationship of cluster-type variables to the longer-period Cepheids, but in a few

characteristics there appear wide differences—discontinuities in the usual progressive connections. One conspicuous discontinuity appears in the frequency of periods, which is illustrated in Table III for the 139 variables of Tables I and I*a*. Attention has been previously called to this matter by Hertzsprung and others. The reason for the two maxima in the frequency-curve must be sought in the dynamics of the stars themselves.

TABLE III

FREQUENCY OF THE PERIODS OF 139 CEPHEID VARIABLES

Period in Days	Number of Stars	Period in Days	Number of Stars	Period in Days	Number of Stars
0.0–0.2.....	2	5.0– 5.5.....	5	13.0–14.0.....	1
0.2–0.4.....	7	5.5– 6.0.....	5	14.0–15.0.....	4
0.4–0.6.....	31	6.0– 6.5.....	6	15.0–16.0.....	3
0.6–0.8.....	4	6.5– 7.0.....	3	16.0–17.0.....	4
0.8–1.0.....	1	7.0– 7.5.....	3	17.0–18.0.....	2
1.0–1.5.....	0	7.5– 8.0.....	6	18.0–19.0.....	2
1.5–2.0.....	2	8.0– 8.5.....	2	19.0–20.0.....	4
2.0–2.5.....	1	8.5– 9.0.....	0	20.0–25.0.....	1
2.5–3.0.....	1	9.0– 9.5.....	1	25.0–30.0.....	2
3.0–3.5.....	4	9.5–10.0.....	2	30.0–35.0.....	0
3.5–4.0.....	6	10.0–11.0.....	4	35.0–40.0.....	2
4.0–4.5.....	7	11.0–12.0.....	2		
4.5–5.0.....	5	12.0–13.0.....	4		

Two other notable differences between the two groups are the space distribution and the space velocities. Hertzsprung has maintained in several notes that the cluster-type stars must be of low luminosity because of the large proper motion of their brightest representative, RR Lyrae ($\mu = 0''.25$), and because of the position of many such stars in high galactic latitude. The closely comparable luminosity of the two groups, however, is established by the luminosity-period curve. Moreover, RR Lyrae has a much larger radial velocity than the ordinary Cepheids, $V_0 = 50$ km/sec., and its proper motion may be an indication of great peculiar velocity rather than of large parallax.

This supposition is strongly supported through spectroscopic observations by Adams of four other cluster-type variables. The smallest radial velocity is -52 km/sec. for RS Boötis; the greatest is -196 km/sec. for XZ Cygni, which has an annual proper motion

of 0".1, according to a determination kindly made at the writer's request by Professor Tucker. If we adopt the parallaxes in Table I, the space velocities of RR Lyrae and XZ Cygni, 400 km/sec., are among the greatest known. The average radial velocity for the longer-period Cepheids is less than 10 km/sec. It is possible, therefore, that the marked contrast between the wide dispersion of isolated cluster-type stars and the galactic concentration of normal Cepheids arises solely from the fact that the velocities of the former are enormous while those of the latter are moderate, in keeping with the motions of most other red and yellow giant stars.

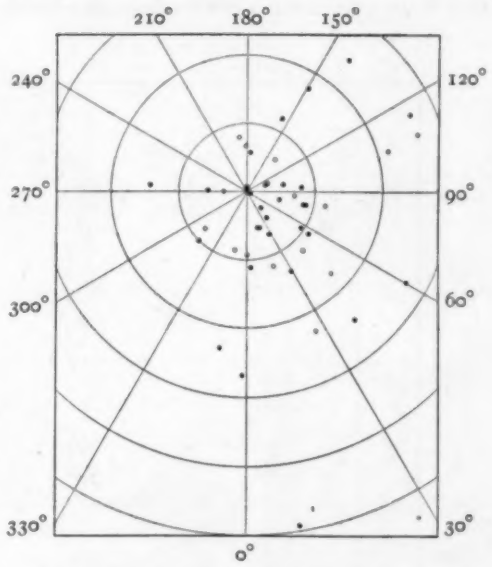

FIG. 1.—Projection on galactic plane of the position of Cepheid variables with periods shorter than one day. The circles are heliocentric, with radii of 1000 parsecs, 2000 parsecs, etc.; galactic longitudes are indicated in the margin. Many of these variables are so far above or below the plane that the diagram does not well represent the distribution in space.

Table IV contains a summary of the distribution of the variables with periods less than one day. The number of such stars is not large; the data are without doubt incomplete and there may be a preference for certain parts of the sky; hence no very definite quantitative conclusions should be based upon the material. The projection of these stars on the galactic plane is illustrated in Fig. 1; the distance from the plane is shown in Fig. 3. The great distances of RU Boötis and SW Herculis, and in particular the significance of the former's position so far from the galactic plane, have been remarked upon previously[1] and will be referred

[1] *Publications of the Astronomical Society of the Pacific*, **29**, 183, 1917.

to again in a subsequent paper. Six cluster-type variables, with $R \sin \beta$ greater than 1750 parsecs, are beyond the bounds adopted as defining the equatorial segment of the Galaxy (Fig. 3). The mean distance from the galactic plane is 960 parsecs for these 45 variables of Table IV; for Cepheids with periods greater than a day it is 150 parsecs—less than one-sixth as much. The parallaxes

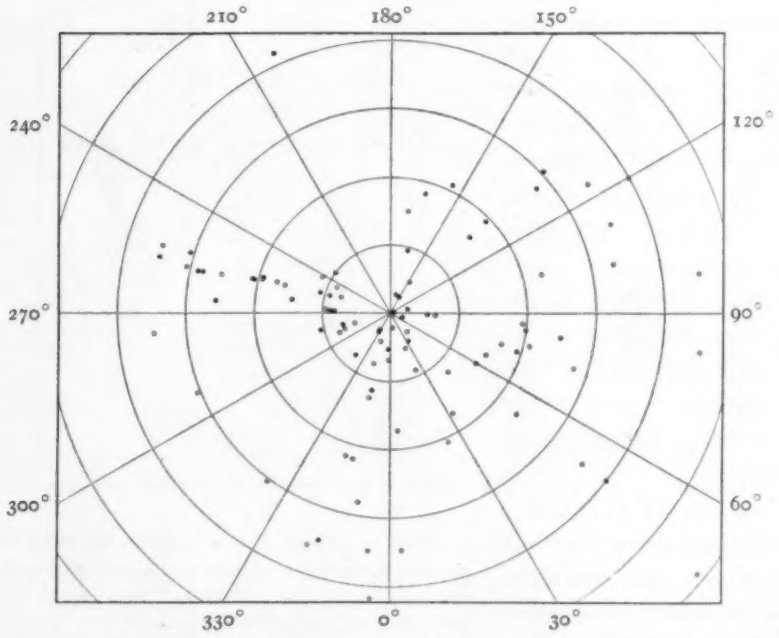

FIG. 2.—Projection on the galactic plane of the positions of Cepheid variables with periods greater than one day. The restriction to the Galaxy is so marked for these stars (see Fig. 3) that the diagram closely represents the distribution in space. The concentration of stars near longitude 255° reflects the systematic study at Harvard of the periods of all Cepheids in a restricted region (*Harvard Circular*, No. 170); it suggests the incompleteness of our data in other longitudes.

of RS Boötis, RU Boötis, XX Cygni, XZ Cygni, and RR Lyrae are the most accurate.

The distribution in the galactic plane of the 94 variables with periods longer than a day is shown in Fig. 2. The space co-ordinates are treated in some detail in Table V, showing the close restriction of ordinary Cepheids to the galactic plane. As a graphical test of

TABLE IV

DISTANCE FROM GALACTIC PLANE OF 45 CEPHEIDS WITH PERIODS LESS THAN A DAY*

VARIABLES NORTH OF GALACTIC PLANE		VARIABLES SOUTH OF GALACTIC PLANE	
Limits of Distance	Number	Limits of Distance	Number
>+1500 parsecs....	7	<−1000 parsecs..	3
+1500 to+1000...	7	−1000 to −500.	5
+1000 to+ 500...	9	− 500 to 0.	8
+ 500 to 0...	6		
Total.....	29	Total.....	16

* Allowance for the position of the sun north of the Milky Way plane would alter these values slightly but would not change the actual dispersion.

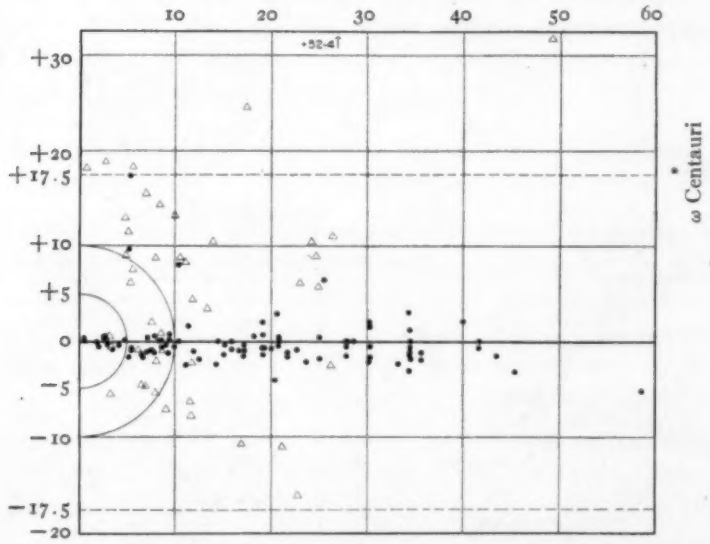

FIG. 3.—Distribution of Cepheid variables. The unit of distance is 100 parsecs. Ordinates are distances from the galactic plane; abscissae are projected distances in the plane; cf. Fig. 5 of the seventh paper. Open triangles and black dots designate respectively cluster-type variables and Cepheids with periods in excess of a day. The nearest globular cluster, ω Centauri, is just outside the boundary of the diagram on the right; RU Boötis, indicated by an arrow, is too far above the plane to fall within the figure. The semicircles with radii of 500 and 1000 parsecs ($\pi = 0''.002$ and $0''.001$) indicate how very distant most of these variables are as compared with the average star of the tenth magnitude or brighter ($\pi > 0''.004$, Kapteyn). Between the broken horizontal lines, ±1750 parsecs, lies the equatorial galactic region devoid of globular clusters.

the relation of galactic concentration to distance from the sun, the values of $R \sin \beta$ are plotted in Fig. 3, against $R \cos \beta$, triangles for cluster-type variables, and dots for those with periods in excess of a day. It is important to note that for the latter the greatest distance from the plane is attained by the star of shortest period, Z Canum Venaticorum, with $R \sin \beta = +17.4$ and period $= 1.890$ days. Its space velocity may be high.

Table V and Fig. 3 reveal no conspicuous divergence from the galactic plane with increasing distance. The indications of a contrary result, obtained in the earlier study,[1] was due partly to the inclusion of a few stars of the RV Tauri type; these stars are probably of lower luminosity than typical Cepheids of like period, and in consequence the computed distances, both radial and from the plane, were much exaggerated.

TABLE V

SPACE DISTRIBUTION OF 94 CEPHEIDS WITH PERIODS GREATER THAN A DAY*

		LIMITS OF $R \cos \beta$ (IN PARSECS)			
		0 to 1000	1000 to 2000	2000 to 4000	>4000
North of Galaxy	No. of stars	14	6	11	2
	Mean $R \sin \beta$	+ 220	+220	+160	+100
	Max. $R \sin \beta$	+1740	+810	+640	+210
	Av. dev. from mean	± 320	± 200	± 140	± 100
South of Galaxy	No. of stars	17	17	23	4
	Mean $R \sin \beta$	− 80	−100	−140	−260
	Max. $R \sin \beta$	− 160	−240	−400	−510
	Av. dev. from mean	± 40	± 60	± 80	± 150
Total No. of Stars		31	23	34	6
Mean $R \sin \beta$	Without regard to sign	150	130	150	210
	With regard to sign	+ 60	− 20	− 40	−140

* Distances are given only to the nearest ten parsecs.

The distribution in longitude (Table VI) of variables with periods greater than one day shows some peculiarities which may be due to incompleteness of the data. There are, for instance, at least 50 stars thought to be Cepheid variables for which periods

[1] *Astrophysical Journal*, 40, 432, 1914.

have not been determined, and probably a great number for which types are not yet known also belong to this class.

The greater number of Cepheids south of the galactic plane is easily accounted for by assuming the sun to be slightly to the

TABLE VI

DISTRIBUTION IN GALACTIC LONGITUDE—NUMBER OF STARS

	0° to 30°	30° to 60°	60° to 90°	90° to 120°	120° to 150°	150° to 180°	180° to 210°	210° to 240°	240° to 270°	270° to 300°	300° to 330°	330° to 360°	Total
North....	0	2	3	3	3	5	1	0	10	2	1	3	33
South....	6	7	9	3	3	1	0	1	13	5	2	11	61
Total....	6	9	12	6	6	6	1	1	23	7	3	14	94

north. In fact the Cepheids should afford a good determination of the distance of the sun from the galactic plane when a more complete list becomes available.

SUMMARY

1. Through the use of the luminosity-period curve the absolute magnitudes and parallaxes have been determined for 174 variables, 139 of which are believed to be perfectly typical members of the Cepheid class (Tables I and I*a*). The average probable error is estimated at 20 per cent.

2. Forty-five variables belong to the cluster type, with absolute luminosities a little more than one hundred times the brightness of the sun. Ninety-four are ordinary Cepheids with periods longer than a day and with luminosities ranging from two hundred to ten thousand times that of the sun. For 35 stars either the type of variation, or the period, or the magnitude is not certain or regular enough to yield final parallaxes (Table II).

3. The distances of Cepheid variables are considerably greater than have been obtained heretofore for individual stars. Less than one-third of them have parallaxes greater than a thousandth of a second. The most distant Cepheids now known are nearly 20,000 light-years from the sun. The nearest globular cluster is at a distance of about 21,000 light-years. (Cf. ω Centauri in Fig. 3.)

4. The numerical evaluation of the distribution in space confirms both the well-known concentration toward the galactic plane of Cepheids with periods greater than a day and the indifference of cluster-type variables to that plane. A plausible explanation of the wide dispersion of the latter is to be found in their relatively very high velocities in space.

MOUNT WILSON SOLAR OBSERVATORY
December 1917

ON THE CAUSE OF THE DISTANCE-VELOCITY EQUATION IN STELLAR MOTIONS

SECOND PAPER

By C. D. PERRINE

Adams and Strömberg[1] object to the treatment of some of the data in my first paper[2] on the foregoing subject and reject the possibility that there can be a direct dependence upon distance from the sun. I am indebted to these gentlemen for sending me an advance copy of their comments.

My investigation rested very largely upon the assumption that there was a close relationship between the size of a star's proper motion and its distance from the sun, an assumption which had been generally accepted and furnished the chief basis of a knowledge of the distances of most of the stars. The conclusions were thought to be sufficiently guarded.

Recent investigations at Mount Wilson and at this observatory seem to throw considerable doubt upon proper motion as a measure of a star's distance. No useful purpose will be served, therefore, by discussing the details of my investigation until such time as this underlying one of distance is settled. Neither is it desirable, in my opinion, to discuss further the evidence in favor of a dependence of velocity upon absolute magnitude. If the suspicions which exist with regard to the parallaxes of the stars should be confirmed, such data will probably need revision also, for it is to be borne in mind that even spectroscopically determined parallaxes are based finally upon *relative* parallax displacements.

I shall therefore confine myself briefly to these doubts about distance and to considerations which are independent of such doubts.

In a recent investigation[3] Adams and Strömberg conclude that "for stars with proper motions less than 0".020 annually the

[1] *Astrophysical Journal*, **47**, 189, 1918.

[2] *Ibid.*, **47**, 179, 1918.

[3] *Ibid.*, **45**, 297, 1917.

parallaxes appear to be nearly independent of proper motion and dependent only upon magnitude."

More recent preliminary results (unpublished) of an investigation here by First Astronomer Zimmer of peculiarities encountered in his work of determining fundamental places with our new Repsold meridian circle, not only tend to confirm the foregoing conclusion of Adams and Strömberg, but throw doubt upon the assumed absolute parallaxes of practically all stars. The details of these investigations will be given by Zimmer in another place. The evidence upon which the doubts rest in this case is too extensive to give here.

In Zimmer's list of stars there are 21 of type B and 2 of type O. If the observed quantities are parallax these stars have large parallaxes. The O and B stars were chosen partly because of their supposed great distance and consequently to furnish a better test of the possibility that the observed effect was parallax. The result has been a complete surprise. The proper motions of these O and B stars are vanishingly small, so that if large parallaxes for them are confirmed, grave doubt is thrown upon the whole question of the relation of parallax to size of proper motion. In other words, without some other criterion it will be impossible to consider proper motion as a reliable indication of distance.

An examination of Strömberg's investigation[1] of the parallax of 700 stars spectroscopically determined reveals some discordances which appear to me to be significant in this connection. The curves in his Fig. 1 show a marked deviation from the ordinary formula, as he points out. His new formula represents the stars of F and G types satisfactorily, but not so the K and M stars. In order better to show these peculiarities I have redrawn these two curves as Fig. 1 of this paper, omitting the broken, straight line. I cannot believe that such consistent divergences of the observations in two distinct cases are purely accidental. If they are not accidental, then one formula will not fit both giant and dwarf stars. We can, however, draw a curve through the giants in both groups which will also fit and include the dwarfs by *shifting it bodily in distance*. Such curves are given in Fig. 2. Is not this an

[1] *Astrophysical Journal*, 47, 10, 1918.

indication also that the derived parallaxes of these more distant stars may be too small?

From the way in which parallactic displacements are obtained it does not seem possible that the observed parallaxes of any stars can be too *large*. If the background of stars used in such investigations is, however, not so distant as has been assumed, then the

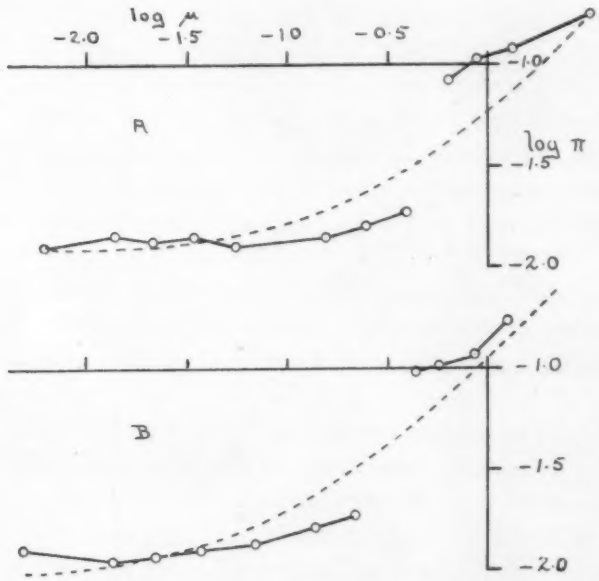

FIG. 1.—Relation between log π and log μ for K and M stars

A—Stars distant from sun's apices
B—Stars near sun's apices
Dotted curves represent formula
$\log \pi = \log A + \log (\mu + c)$

accepted absolute parallaxes may be too *small*. The evidence upon which the distance of this background of stars has been accepted as great is not lightly to be thrown aside. But in view of the difficulty of obtaining directly the distances of these stars, and the contrary evidence which is at hand, it is certainly permissible to consider the possibility of the absolute parallaxes in general being too small.

It may be noted also that Strömberg's curves of parallax for the F and G stars show some slight indications of the discontinuity which is so marked in the K and M stars. It would not attract attention, however, except for the large break in the K and M stars.

The discontinuity in the parallaxes of the K and M stars found by Strömberg, the conclusions of Adams and Strömberg regarding

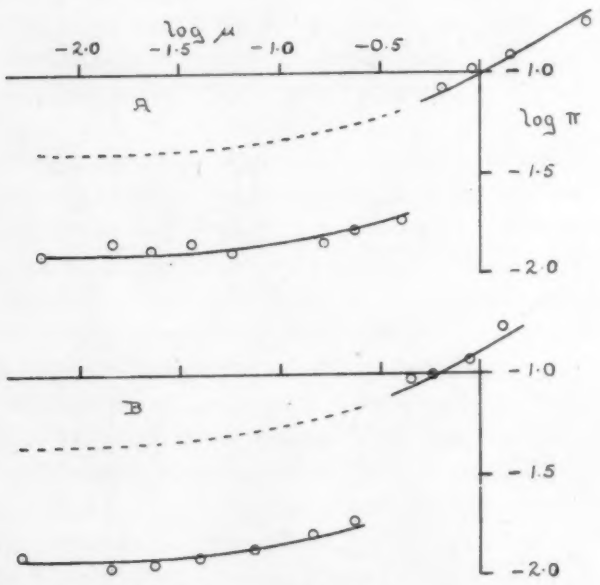

FIG. 2.—Relation between log π and log μ for K and M stars

Dotted portions of curves are extrapolations on the assumption that the small parallaxes may be too small.

the relation between parallax and proper motion in the case of the stars of small μ, but above all the suspicions raised by Zimmer's investigations and the consequent effects of a general change in parallax upon all absolute magnitudes, if confirmed, will necessitate a re-examination of practically all the absolute magnitudes after the question of parallax has been definitely answered. Should the present suspicions in the matter of parallax be confirmed, it seems certain that the corrections required would be greatest among the stars which are now classed as very bright.

The foregoing considerations seem to render useless any attempt at present to determine the distances of the different groups of stars of small μ of Table I of my former paper. To this extent the objection of Adams and Strömberg to that evidence appears to be upheld, at least for the present.

An examination of the frequency-curves[1] of absolute magnitudes by Adams and Joy is of some interest. The mean magnitudes of the giants are rather consistent and about +1 for all of the spectral classes given. On the other hand the magnitudes of the dwarfs decrease consistently from $+4\frac{1}{4}$ for the stars of type F to +11 for the stars of type M. A consideration of the absorption effects of their atmospheres seems to furnish a reason for the decline in brightness of the "dwarfs." The same consideration seems to require an explanation for the nearly uniform brightnesses of the "giants" of all spectral classes.

It is somewhat suggestive in this connection that the stars (K and M) which show the striking discontinuity in parallax are the same which show the greatest separation as to absolute magnitude.

An attempt was made to decide, by means of least-square solutions from 210 stars whose parallaxes had been measured spectroscopically, whether the dependence was upon absolute magnitude, or upon distance, or upon both. Ellipsoidal motion was directly allowed for. The results showed a larger dependence upon distance than upon absolute magnitude, but, on account of the small amount of data available and the suspicions which now attach to stellar parallax in general, little weight is attached to them.

With regard to the objection raised to the application to radial velocities of factors which will reduce all the stars to the same proper motion, the manifest uncertainties in the present case seem to render superfluous a discussion of my procedure. It is very often desirable and a common practice to attempt to render homogeneous groups of data within reasonable limits. If the size of μ is an index of velocity rather than of distance, as now seems possible, the effect of my reduction was to render the velocities of the groups of different apparent magnitudes more comparable (and perhaps

[1] *Astrophysical Journal*, 46, 335, 1917.

necessary), but had little bearing on the factor of distance. The classification according to apparent magnitude may be one according to distance also, but that this is strictly the case seems doubtful.

It seems to me that the effect of a large-distance dispersion in the stars of small μ is not necessarily of such great importance as suggested by Adams and Strömberg. I was dealing with the means of six groups, four of them containing from 169 to 317 stars each. Granting that there is such a dispersion as considered by them, 100 to 1 (which in the light of present suspicions seems doubtful), the *means* of such considerable groups can scarcely differ greatly. It seems to me doubtful if the dispersion in distance of these groups is likely to be much greater than their dispersions in velocity, in which case the errors would be comparable.

The entire matter of these dependencies may be looked at in another way. In practically all of these classifications the great majority of the velocities are low. This is also true to a considerable extent in the groups of fainter stars and those of large μ. It was found that if velocities over 30 km[1] were rejected in the investigation of a relation to spectral class no such relation remained. This and other investigations show that it is almost entirely the larger velocities which cause these different apparent relations. These large velocities appear to show a strong preference for the vertices of preferential motion. The direct inference from this is that the observed relations are in reality, largely at least, effects of stream-motion, thus corroborating the results of the direct classification in which stream-motion was one of the factors.

The possible unconscious selection of large velocities.—The fact that the absolutely faint stars in the lists of radial velocities have resulted from selections of stars largely because of their large proper motions raises the question whether such an unconscious selection has not also led to high velocities generally in these stars. A list of stars selected because of their large proper motions must lead, not only to nearness and absolute faintness, but also to unusually large velocities. If there is little or no relation of distance to size of proper motion, then variations in the size of proper motion become

[1] In the 1800 stars used by me only 12 per cent have radial velocities of 30 km or over.

in general indications of differences of velocity, and the possibility of an unusual proportion of large velocities among the absolutely very faint stars becomes accentuated. As practically all of such very faint stars have come into the lists because of their large (often excessive) proper motions, it seems to me very probable that such stars are not fair samples of their respective absolute magnitudes—that in general they may be the largest velocities of their classes, and that when stars of much fainter apparent brightness have been systematically investigated the average velocities now found may be greatly reduced.

Adams and Strömberg lay stress upon the consequence arising from the assumption of a dependence upon distance, that

> such a relationship would assign to the sun an extraordinary position in the stellar system which we have no reason for believing that it holds. It is a star of very moderate size and mass and is known to lie at a great distance from the center of the galaxy. It would seem far more probable that any relationship between velocity and distance would be one in which the latter was measured from some much more fundamental reference point than our sun.[1]

Such a consequence of a dependence upon distance was not overlooked in my first investigation, although it was not discussed. When my first paper was written I had in mind chiefly regions (an effect of cosmical matter which appears to exist in galactic regions), as is evidenced by the following expression:

> Some hypothesis in which distance is concerned, probably rather in the nature of regions, seems to me to offer a more satisfactory explanation of the observed facts. Taking all of these into consideration, I have no hesitancy in expressing the belief that distance in some manner plays a considerable part in the phenomena in question. If my hypothesis is correct the chief factor is distance or region, and the absolute magnitudes, spectral classes, and changes of velocity follow from the different conditions existing in the near and distant regions of our stellar system. This would explain also the very close relation of all of these factors.

For such a scheme it is not necessary that the observer should be at the center of the stellar system. It is necessary only that he should be somewhere near the middle of a region (not necessarily exactly circular) where the postulated cosmical matter is rather scarce, which region is surrounded in a general way by others richer

[1] *Astrophysical Journal*, **47**, 191, 1918.

in such matter. It is possible to conceive of many such regions within a stellar system, whether it be of a general ring form or spiral.

There may be, however, an even closer relation to distance due entirely to stream-motion. For an observer situated in a stream of stars, especially if curved, there would be a tendency for the radial velocity to depend upon distance from the observer. A little consideration will make this plain. If, for example, the observer is situated in a stream of stars which is rather sharply curved, and the principal motion of the stars is in the direction of the stream, the stars will appear to have a preferential motion nearly in the direction of a *tangent to the stream at the position of the observer*. In such a case the near stars will show the greatest preferential motion and the largest radial motions, which will be in the direction of the stream-motion, and there will obviously be a real dependence of the phenomenon upon the position of the observer. Something similar might result if the systematic motions were radial.

In conclusion, I recognize, and so stated in my first paper, the necessity of confirming the conclusion that the near stars have, in general, larger individual velocities than the more distant ones. Such a dependence upon the position of the observer is theoretically at least possible. In my opinion the conclusion that the smaller stars are moving more rapidly than the large ones also requires confirmation, although I can see reasons for such a condition, and some evidence favors it. It has yet to be shown, however, what the effect would be of directly eliminating stream-motion from the absolute magnitudes. It may be that there are dependencies upon both magnitude and distance.

It is suggested that a possible unconscious selection of large velocities among the absolutely faint stars may be partly responsible for the apparent dependence upon magnitude as well as some others of the dependencies observed.

I look forward to the time when the present uncertainties as to parallax will be resolved and enough data will become available to enable me to continue the investigation with hope of a decisive result.

Observatorio Nacional Argentino, Cordóba
July 25, 1918

THE CHANGE IN BRIGHTNESS, SPECTRUM, AND TEMPERATURE OF NOVA AQUILAE NO. 3

By MENTORE MAGGINI

Using my Heterochrome Photometer[1] I have observed Nova Aquilae during the interval June 12—September 22. The observations were made at wave-lengths 645 $\mu\mu$, 558 $\mu\mu$, 412 $\mu\mu$. As 558 $\mu\mu$ is about the mean wave-length corresponding to the magnitudes in natural light, we can assume that comparisons at 558 $\mu\mu$ are equivalent to the visual magnitudes. Comparisons were executed according to the following scheme: The ocular tube is placed at the distance 30 mm from the focus and three comparisons (star No. 1, Nova, star No. 2) were made, then three (star No. 2, Nova, star No. 1). A complete set in three radiations requires about twenty-five minutes.

Magnitudes of comparison stars at 558 $\mu\mu$ are the Harvard magnitudes. At 645 and 412 $\mu\mu$ they were determined with the photometer as follows: I have adopted for stars of spectral type A the magnitude in all radiations equal to that of *Harvard Photometry;* by selecting a considerable number of stars from types Bo to Mo the scale of magnitude at 645 $\mu\mu$ and 412 $\mu\mu$ was obtained, measuring their difference from the Ao stars and making the difference in the three radiations. The values were then plotted against the types of these stars, and smooth curves were drawn through the several points. These curves provide the means of converting determinations of magnitude for the three radiations into spectral type. According to these curves the relation between spectral type and magnitude-differences can be regarded as linear, i.e.,

$$\begin{aligned} m_{558}-m_{645} &= +0.198\ s \\ m_{412}-m_{558} &= +0.353\ s \\ m_{412}-m_{645} &= +0.526\ s \end{aligned} \qquad (1)$$

[1] *Comptes Rendus*, **166**, 284, 1918; *Bulletin Astronomique*, **35**, 131, 1918; *Popular Astronomy*, **26**, 380, 1918.

in which s has the values $-1, 0, +1$, etc., according as the spectrum is Bo, Ao, Fo, etc.[1] Table I (p. 305) contains the observed magnitudes of Nova Aquilae.

These observations were plotted on Fig. 1. The curves show that the brightness of the Nova increases according as the refrangibility of radiation diminishes. During the greatest brightness its color was white, as α Lyrae; correspondingly the brightness at 412 $\mu\mu$ was greater than at 645 and 558 $\mu\mu$. Conspicuous changes were observed in the light. A species of pulsation is recorded with regular intervals on the dates June 18, 24, 30, July 11, 30, in which the brightness at 645 and 412 $\mu\mu$ has the least difference; hence the color of the Nova passed from the red toward the white. The period of these changes is about six days.

On the other hand if we consider the change at 558 $\mu\mu$, i.e., in the visual light, we find a pulsation having a period of about 10–13 days, and the minima fall at the following dates:

June	17	
		10^d
	27	
		12
July	9	
		12
	21	
		12
Aug.	2	
		13
	15	

This period can also be of 24–26 days with a secondary minimum.

[1] If we consider the ratios $\frac{645}{558}, \frac{558}{412}, \frac{645}{412}$, they show the energy-distribution in the different classes. We have the following table:

	$\frac{645}{558}$	$\frac{558}{412}$	$\frac{645}{412}$	Merrill
Bo	0.83	0.72	0.60	1.0
Ao	1.00	1.00	1.00	
Fo	1.20	1.39	1.62	2.5
Go	1.44	1.92	2.76	
Ko	1.73	2.65	4.58	6.0
Mo	2.07	3.67	7.61	6.5

The last column contains the ratio of red to blue light measured by Merrill ("Application of Dicyanin to the Photography of Stellar Spectra." *Scientific Papers of the Bureau of Standards*, No. 318) in good agreement with my results.

TABLE I

No.	1918	G.M.T.	Mag. 645 μμ	Mag. 558 μμ	Mag. 412 μμ	Notes	No.	1918	G.M.T.	Mag. 645 μμ	Mag. 558 μμ	Mag. 412 μμ	Notes
1..	June 12	8^h35^m	$0^M.26$	$0^M.20$	$-0^M.13$	II	39..	July 27	8^h46^m	$3^M.11$	$3^M.91$	$4^M.93$	III
2..	13	8 45	0.55	0.73	+1.33	II	40..	28	8 53	3.10	3.79	4.75	I
3..	14	8 45	1.00	1.14	1.52	II	41..	29	8 58	3.02	3.85	4.85	I
4..	15	9 30	1.02	1.10	1.75	II	42..	30	8 55	3.18	3.80	4.50	I
5..	16	8 55	1.09	1.70	2.35	II	43..	31	8 40	3.03	3.88	4.58	I
6..	17	9 0	1.73	1.91	2.36	II M	44..	Aug. 1	8 20	3.18	4.30	5.31	I
7..	18	9 10	1.79	1.75	1.90	II M	45..	2	8 0	3.20	4.34	5.39	I
8..	20	9 15	1.70	2.24	3.34	II M	46..	4	8 5	3.08	4.30	5.35	I
9..	21	9 45	1.82	2.45	3.50	III M	47..	7	8 17	3.10	4.10	5.35	I
10..	22	9 10	2.00	2.47	3.54	I M	48..	8	7 45	3.17	4.20	5.25	I
11..	23	9 30	2.25	2.92	3.32	II M	49..	10	8 0	3.02	4.20	5.48	I
12..	24	8 43	2.73	3.13	3.42	I M	50..	11	8 10	3.05	4.35	5.50	I
13..	25	8 40	2.51	3.28	4.62	I M	51..	12	8 43	3.28	4.37	5.63	I
14..	26	8 48	2.82	3.65	5.01	III	52..	13	8 35	3.32	4.45	5.52	III
15..	27	8 52	3.02	3.89	5.37	I	53..	14	8 30	3.17	4.45	5.60	I M
16..	28	8 53	3.34	3.84	5.02	II	54..	15	8 38	3.30	4.50	5.42	I M
17..	29	9 12	2.92	3.41	4.40	I	55..	16	9 0	3.18	4.40	5.65	I M
18..	30	9 25	3.02	3.35	4.15	II	56..	17	8 2	3.20	4.40	5.53	I M
19..	July 1	9 30	2.73	3.34	4.60	I	57..	18	8 33	3.22	4.50	5.50	III M
20..	2	9 0	2.59	3.25	4.45	I	58..	20	9 15	3.70	4.71	5.52	I
21..	4	9 15	2.78	3.22	4.15	I	59..	21	9 30	3.73	4.75	5.51	I
22..	5	9 30	2.73	3.22	4.15	III	60..	23	9 0	3.75	4.60	5.55	I
23..	6	9 0	2.60	3.30	4.65	III	61..	24	8 40	3.60	4.75	5.60	I
24..	7	9 20	2.65	3.34	4.40	I	62..	25	9 0	3.45	4.70	5.73	II
25..	8	9 10	3.12	3.77	5.00	I	63..	27	9 10	3.40	4.40	5.80	I
26..	9	9 0	3.25	3.86	5.12	II	64..	28	9 9	3.72	4.50	5.82	II
27..	11	9 30	3.40	3.83	5.01	II	65..	31	8 10	3.80	4.80	5.80	I
28..	12	10 0	3.56	3.95	4.74	I	66..	Sept. 3	8 16	3.75	4.88	5.85	II
29..	13	8 55	3.38	3.72	4.60	I	67..	4	8 8	3.68	4.88	5.85	I
30..	14	9 15	3.23	3.82	4.81	II	68..	5	9 15	3.85	4.80	5.82	I
31..	15	9 15	3.22	3.78	4.87	I M	69..	8	7 18	3.80	4.80	5.65	II
32..	16	9 5	3.22	3.91	5.00	I M	70..	10	7 35	3.72	4.85	5.62	I
33..	17	9 10	3.23	3.79	4.85	I M	71..	11	7 7	3.60	4.85	5.60	I
34..	19	8 35	3.23	3.92	5.04	I M	72..	13	7 50	3.60	4.90	5.57	I M
35..	21	9 21	3.36	4.25	5.23	I M	73..	14	7 0	3.60	4.90	5.55	I M
36..	24	9 15	3.01	3.86	5.03	I M	74..	16	8 8	3.60	4.90	5.45	I M
37..	25	9 7	2.98	3.90	5.15	I M	75..	21	8 15	3.82	4.43	5.15	II M
38..	26	8 40	2.90	3.86	5.12	I M	76..	22	7 33	3.28	4.80	5.72	II M

I = Very fair. II = Sky fair. III = Sky veiled at the horizon. M = Moonlight.

SPECTRAL TYPE

The relations (1) have been used in the determination of spectral type; magnitude-differences $m_{412} - m_{645}$ were taken and spectral type deduced from the last equation (1); the results are in the fourth column of Table II and in Fig. 2. They show that at the first observation (June 12) the Nova was of spectral type B6. In general during the month of June the spectrum changed from

TABLE II

No.	1918	$\frac{i_{445}}{i_{412}}$	Sp.	T	No.	1918	$\frac{i_{445}}{i_{412}}$	Sp.	T
1	June 12	1.28	B6	14500°	39	July 27	5.35	K4	4300°
2	13	2.05	F4	6400	40	28	4.57	K1	4500
3	14	1.61	F0	7300	41	29	5.40	K4	4200
4	15	1.96	F3	6600	42	30	3.37	G4	5000
5	16	3.19	G3	5200	43	31	4.17	G9	4700
6	17	1.79	F2	6900	44	Aug. 1	7.11	K9	3900
7	18	1.11	A2	9700	45	2	7.52	M0	3800
8	20	5.45	K4	4200	46	4	8.09	M2	3700
9	21	4.70	K1	4400	47	7	7.94	M2	3800
10	22	4.13	G8	4700	48	8	6.79	K8	3900
11	23	2.68	G0	5600	49	10	9.64	M6	3500
12	24	1.89	F3	6700	50	11	9.55	M5	3600
13	25	7.24	M0	3800	51	12	8.71	M3	3700
14	26	7.52	M0	3800	52	13	7.59	M1	3800
15	27	8.71	M3	3600	53	14	9.38	M5	3600
16	28	4.70	K1	4400	54	15	7.05	K9	3900
17	29	3.91	G7	4800	55	16	9.73	M6	3500
18	30	2.83	G1	5500	56	17	8.55	M3	3700
19	July 1	5.60	K5	4200	57	18	8.17	M2	3700
20	2	5.55	K5	4200	58	20	5.35	K4	4200
21	4	3.53	G5	5000	59	21	5.15	K3	4300
22	5	3.70	G6	4900	60	23	5.25	K3	4200
23	6	6.61	K8	4000	61	24	6.31	K7	4000
24	7	5.01	K2	4300	62	25	8.17	M2	3700
25	8	5.65	K5	4200	63	27	9.12	M4	3600
26	9	5.60	K4	4200	64	28	6.92	K9	3900
27	11	4.41	K0	4600	65	31	6.31	K7	4000
28	12	2.97	G2	5300	66	Sept. 3	6.92	K9	3900
29	13	3.08	G3	5300	67	4	7.38	M0	3800
30	14	4.29	G9	4600	68	5	6.14	K7	4000
31	15	4.57	K1	4500	69	8	5.50	K4	4200
32	16	5.15	K3	4300	70	10	5.75	K5	4100
33	17	4.45	K0	4500	71	11	6.31	K7	4000
34	19	5.30	K4	4300	72	13	6.14	K7	4000
35	21	5.60	K5	4200	73	14	6.03	K6	4100
36	24	6.43	K7	4000	74	16	5.50	K4	4200
37	25	7.38	M0	3800	75	21	3.40	G5	5000
38	26	7.73	M1	3800	76	22	9.46	M5	3600

B to M; in July it remained at about K; in August and September it was of type M.[1]

It is clearly evident that in the spectral type we find recorded the fluctuations in the brightness. At the dates June 12, 18, 24, 30, we have a return of spectrum toward the types F and A; this phenomenon may be seen also in July and August. In the following

[1] These are of course only the inferences as to spectral type; the spectroscopic observations do not show such changes.—Ed.

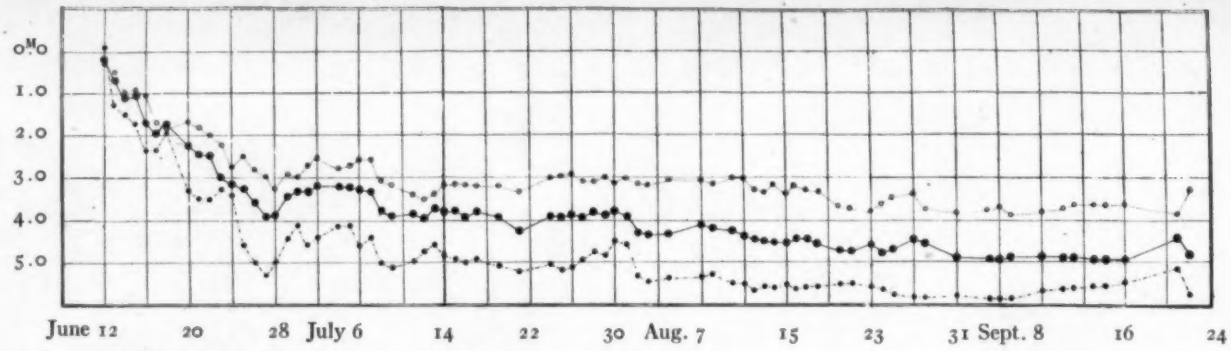

FIG. 1.—Above, empty circles: brightness at λ 645 μμ; Central, large disks: brightness at λ 558; Below, small disks: brightness at λ 412

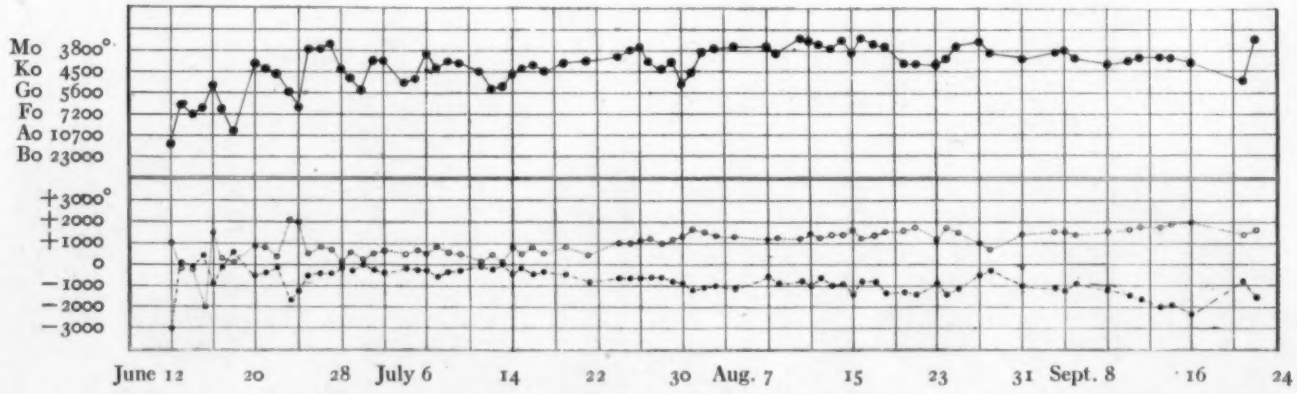

FIG. 2.—Above: Change in spectrum and temperature, $T_{(412-645)}$; Empty circles: differences, $T_{(412-645)} - T_{(558-645)}$; Black disks, below: differences, $T_{(412-645)} - T_{(412-558)}$.

table are the dates, spectral types, and amplitude of fluctuations in spectral classes:

Min.		Max.		Ampl.
June 12.....	B6	June 16....	G_3	2.7
18.....	A_2	20....	K_4	3.2
24.....	F_3	27....	M_3	3.0
30.....	G_1	July 2....	K_5	1.4
July 30.....	G_4	Aug. 4....	M_2	1.8

We see that the amplitudes diminish.

EFFECTIVE TEMPERATURE

Having the brightness in three special radiations we have determined for every observation the effective temperature of the Nova. According to Planck's law the most approximate relation between color and temperature of a body is

$$J = C\lambda^{-5}(e^{\frac{c}{\lambda T}} - 1)^{-1},$$

in which J is the energy at wave-length λ, T the effective temperature, C and c are constants. For two regions of spectrum, λ_1 and λ_2, we have the ratio:

$$\frac{J_1}{J_2} = \left(\frac{\lambda_2}{\lambda_1}\right)^5 \frac{e^{\frac{c}{\lambda_2 T}} - 1}{e^{\frac{c}{\lambda_1 T}} - 1}$$

Now if for a star i_1 and i_2 are the observed brightness at λ_1, λ_2, and if $J_1 = Ki$, and $J_2 = Ki_2$, we have

$$\log\left(\frac{J_1}{J_2}\right) = \log K + \log\left(\frac{i_1}{i_2}\right) = \log K + 0.4(m_2 - m_1).$$

Hence for a star of known temperature T_0

$$\log\left(\frac{J_1'}{J_2'}\right) = \log K + 0.4(m_2' - m_1').$$

Subtracting we have:

$$\log\left(\frac{J_1}{J_2}\right) - \log\left(\frac{J_1'}{J_2'}\right) = 0.4[(m_2 - m_1) - (m_2' - m_1')].$$

And, according to Planck's law,

$$0.4[(m_2-m_1)-(m_2'-m_1')]=$$
$$[\log(e^{\frac{c}{\lambda_1 T}}-1)-\log(e^{\frac{c}{\lambda_1 T}}-1)]-[\log(e^{\frac{c}{\lambda_1 T_0}}-1)-\log(e^{\frac{c}{\lambda_1 T_0}}-1)].$$

This expression provides the means of determining effective temperature T of the Nova, when we know the magnitude-differences in two radiations and the magnitude-differences corresponding to the known temperature T_0.

I have determined the temperature of the Nova for each date, introducing in the expression the quantities:

$$c=14200^{1}$$
$$T_0=10700^{\circ}$$

The temperature T_0 corresponds to spectral type Ao according to the Potsdam results.

The values of effective temperature were deduced from the magnitude=differences $m_{412}-m_{645}$; they are in Table II. Two further sets of values were also obtained from the magnitude=differences $m_{558}-m_{645}$ and $m_{412}-m_{558}$; these temperatures are different from that of Table II. This fact is a sign that the distribution of energy in the spectrum of the Nova has changed from day to day. The temperature-differences $T_{(412-645)}-T_{(558-645)}$ and $T_{(412-645)}-T_{(412-558)}$ were formed and plotted in Fig. 2. We see that the greatest and irregular changes are during the period of greatest luminosity. Since Planck's law refers to the black body, the following conclusions may be deduced from Fig. 2:

1. Energy-distribution in the spectrum of the Nova has changed; the Nova does not follow the law of the black body.

2. Except in the first days of observation, temperature $T_{(412-645)}$ is constantly superior to $T_{(558-645)}$ and inferior to $T_{(412-558)}$.

3. The temperature-differences increase according as the brightness of the Nova diminishes, hence the difference from the black body increases.

FLORENCE
October 1918.

[1] Holborn und Valentiner. *Sitzungsberichte der Akademie Berlin*, 1906, 811.

THE PERIOD OF *004872* V TUCANAE

By BERNHARD H. DAWSON

The variability of the star V Tucanae was discovered by Miss Annie J. Cannon from an examination of plates taken at Arequipa and was announced in *Harvard Circular*, No. 134, where the star is designated H. V. 3021. In *Astronomische Nachrichten*, No. 4230, it was given the provisional designation 185:1907, in accordance with the custom of that periodical. The Variable Star Committee of the Astronomische Gesellschaft, in their list published in *Astronomische Nachrichten*, No. 4278, gave it the definitive name V Tucanae, and it first appears in the *Vierteljahrsschrift* of that Society in the "Katalog und Ephemeriden für 1909" in Vol. 44.

The star is *C.P.D.* $-72°$ 69, magnitude 9.9, and, so far as the writer knows, it has not been observed on the meridian. Its place according to the *C.P.D.* is

$$\alpha = 0^h\ 47^m\ 15^s; \quad \delta = -72°\ 40'.8, \quad 1875.0$$

from which are derived

$$\alpha = 0^h\ 48^m\ 10^s; \quad \delta = -72°\ 32'.6, \quad 1900.0$$
$$\lambda = 312°\ 18'.9; \quad \beta = -64°\ 9'.9, \quad 1900.0$$
$$\log. 8.308 \cos \beta = 0.55878$$

The La Plata observations are comparisons by Argelander's method, using several neighboring stars whose co-ordinates and assumed magnitudes are given in Table I. As there are no stars in the neighborhood as faint as the variable with photometrically determined magnitudes, the adopted magnitudes have been derived from the observations, with the more or less arbitrary assumption that the light-step is equal to a tenth of a magnitude in all parts of the scale. The observations themselves are given in Table II, which also contains other data explained later. Of the 148 observations 63 are well toward the middle of the eclipse, giving magnitudes of 10.48 or fainter on the scale adopted, and were assigned full weight in the determination of period; 28 others during eclipse but

not so near minimum were given half weight, and the rest were considered as of no weight in the determination and were disregarded except in drawing the light-curve. From the depth of the primary minimum it was seen that the secondary minimum would be too shallow to be accurately observed by this method, and no attempt was made to observe that part of the curve further than a few comparisons to eliminate the possibility of a period half of that here derived.

TABLE I

COMPARISON STARS

Designation Employed	C. P. D. Number	1900		Adopted Magnitude
		$\Delta\alpha$	$\Delta\delta$	
r	−72°70	+0^{m}11^s	+13′.6	9.69
t	73 49	−1 4	−19.4	9.79
s	72 72	+2 41	+ 7.6	9.82
q	72 65	−5 24	−13.2	9.95
y	.....	+3 21	− 6.8	10.08
w	72 71	+1 59	− 8.6	10.14
x	.....	+0 30	− 4.1	10.31
λ	.....	+2 26	−10.8	10.45
z	.....	−0 34	+ 4.2	11.55
r	.....	−0 36	+ 5.9	11.67
ξ	.....	−0 42	− 0.7	11.79
a	.....	+0 4	+ 0.5	12.25

The preliminary reduction was made by sketching a curve from the observations of each eclipse and taking the mid-point of the best determined horizontal chord as the time of minimum. These provisional minima were weighted arbitrarily, and a solution was made for preliminary values of epoch and period, with which an ephemeris was computed. Calling T the time of minimum given by this ephemeris, the quantity $t-T$ was derived for each observation, and all the observations were united upon a single plot with the arithmetical value of $t-T$ as abscissa. Through these points was drawn the curve which seemed best to represent them, and from this curve, with magnitude as argument, a value of $T-t$ was read off for each observation during eclipse and applied to the time of observation to obtain a value of the geocentric time of the corresponding minimum. The several times obtained for each minimum

TABLE II

Visual Observations

Date *.	2421	Mag.	Red. to Min. o^{d}001	Geocentric Min.	Date	2421	Mag.	Red. to Min. o^{d}001	Geocentric Min.
Oct. 19, 1917	521.622	10.04	.....	Obs.	Oct. 31, 1917	533.475	9.88	.....	
	.691	11.14	−14	.677		.536	9.95	.....	
	.732	9.96	.....	Comp.		.625	9.94	.....	Obs.
Oct. 20.....	522.504	10.14	+50*	.679	Nov. 3.....	536.478	12.01	0	.483
	.535	10.72	+22			.492	11.75	− 4	Comp.
	.548	11.65	+ 5		Nov. 5.....	538.737	9.99	.....	.485
	.578	10.81	−21	Obs.	Nov. 8.....	541.654	10.03	.....	
	.588	10.14	−50*	.553		.666	10.08	.....	
	.640	10.06	.....	Comp.		.681	10.36	+35*	
Oct. 21.....	523.509	9.90	.....	.550		.692	10.38	+34*	
	.602	10.01	.....			.700	10.88	+19	
	.650	10.01	.....			.710	11.55	+ 7	
	.707	10.03	.....			.720	11.15	−14	
	.762	10.04	.....			.728	10.93	−18	Obs.
Oct. 22.....	524.675	9.98	.....			.733	10.48	−30	.712
Oct. 23.....	525.538	10.02	.....			.741	10.33	−36*	Comp.
Oct. 25.....	527.468	9.87	.....			.748	10.24	−42*	.711
	.750	10.26	+40*	Obs.		.757	10.20	−45*	
	.790	10.93	−18	.778	Nov. 9.....	542.488	9.87	.....	
	.823	10.11	.....	Comp.		.517	9.95	.....	
Oct. 27.....	529.467	10.07	.....	.776		.532	10.05	.....	
	.495	10.62	+25	Obs.		.562	10.80	+21	
	.520	11.78	− 3	.518		.580	11.97	0	
	.554	10.26	−40*	Comp.		.589	11.70	− 6	
	.570	10.11	.....	.518		.603	10.97	−17	Obs.
Oct. 29.....	531.490	9.88	.....			.613	10.38	−34*	.582
	.530	9.90	.....			.625	10.14	−50*	Comp.
Oct. 30.....	532.508	9.92	.....			.646	9.97	.....	.582
	.535	10.04	.....			.673	10.00	.....	

Nov. 12, 1917.....	545.552	9.95	.....		Feb. 26, 1918.....	651.507	10.06	.....	
	.595	9.95	.....			.512	10.08	.....	
Nov. 16.....	549.587	10.18	−46*	Obs.		.536	10.06	.....	
	.640	10.00	.....	.541		.558	10.21	.....	
	.666	10.00	.....	Comp.		.565	10.16	.....	
	.687	10.00	.....	.550		.583	10.21	.....	
Nov. 17.....	550.626	10.00	.....			.616	10.01	.....	
					March 3.....	656.585	10.01	.....	
Jan. 5, 1918.....	599.553	10.05	.....			.600	10.18	+46*	
	.579	10.08	.....			.614	10.31	+37*	
Jan. 9.....	603.542	11.83	0			.653	11.08	+15	
	.554	11.56	− 7			.663	11.42	+ 9	
	.563	11.13	−14	Obs.		.668	11.52	+ 7	
	.572	10.93	−18	.549		.672	11.87	0	
	.588	10.30	−37*	Comp.		.680	11.37	−10	
	.596	10.22	−43*	.548		.683	11.22	−13	
	.619	10.06	.....			.687	11.08	−15	
	.632	10.11	.....			.691	10.88	−19	
	.682	9.98	.....			.694	10.73	−22	
Jan. 14.....	608.564	10.02	.....			.700	10.83	−20	Obs.
	.612	10.02	.....			.708	10.71	−23	.673
	.655	10.02	.....			.713	10.61	−26	Comp.
	.702	10.06	.....			.732	10.31	−37*	.674
	.708	10.18	+46*		March 4.....	657.512	10.31	+37*	
	.725	10.28	+38*			.528	11.12	+14	
	.749	11.08	+15	Obs.		.539	11.52	+ 7	
	.757	11.23	+12	.767		.548	11.57	− 6	
	.765	11.52	+ 8	Comp.		.553	11.27	−12	
	.772	11.82	− 1	.773		.557	11.05	−15	
Feb. 18.....	643.599	11.24	+12	Obs.		.562	10.82	−20	Obs.
	.605	11.72	+ 4	.611		.570	10.68	−24	.545
	.635	10.83	−20	Comp.		.578	10.61	−26	Comp.
	.642	10.31	−37*	.610		.588	10.31	−37*	.545

TABLE II—*Continued*

Date	2421	Mag.	Red. to Min. 0^d001	Geocentric Min.	Date	2421	Mag.	Red. to Min. 0^d001	Geocentric Min.
July 5. 1918.....	780.711	9.76	.....		Aug. 6, 1918.....	812.508	10.20	+44*	
July 10.....	785.626	9.80	.....			.511	10.20	+44*	
Aug. 5.....	811.645	10.01	.....			.520	10.41	+32*	
	.651	10.05	.....			.529	10.78	+21	
	.668	10.37	+34*			.540	10.98	+17	
	.675	10.83	+20			.548	11.28	+12	
	.691	11.96	0			.560	12.03	0	
	.696	11.77	− 3			.577	11.42	− 9	
	.704	11.28	−12	Obs.		.582	10.98	−17	Obs.
	.708	11.13	−14	.693		.589	10.88	−19	.561
	.713	10.88	−19	Comp.		.597	10.51	−29	Comp.
	.718	10.30	−38*	.693		.607	10.31	−37*	.564
	.726	10.00	.....						

were then averaged, giving half weight to observations near the beginning and end of the eclipse, and the mean times thus obtained were reduced to the sun. These heliocentric times of minimum were then used to determine the elements of variation, with the resulting formula:

$$\text{Minimum} = \text{J. D. } 2421594.8368 + (0.870910 \pm 0.000009)\, E.$$

On the basis of this period the observations during eclipse were collected to a single revolution and plotted. As there was no a priori reason for supposing the eclipse unsymmetrical the variation was assumed to be symmetrical, the observations were grouped according to time from minimum, and a smooth curve was drawn through the resulting normal points.

As the period so determined did not represent all the data given in the original announcement of variability, the matter was allowed to rest at this point for some time. The minima of August 5 and 6 were observed to check the period derived, and later, through the kindness of Miss Cannon, the source of the discrepancy was made clear. The last plate mentioned in *Harvard Circular*, No. 134, was given as of August 6, 1906, whereas the correct date is August 8, 1906. The time of mid-exposure of each of the plates referred to was also communicated. These data, together with the computed times of minimum, are given in Table III. Upon their receipt the light-curve already determined was used to derive new observed epochs of minimum, giving the quantities which are included in Table II under the head "Red. to Min.," in which the quantities with asterisk (*) correspond to the observations which were given half weight. In the column "Geocentric Min." the upper of each pair of numbers is the mean of the observed times. After reduction to the sun these were combined with the plates 2790, 2791, 3901, and 4477, giving unit weight to each plate, and a solution was made for epoch and period by the method of least squares, using equations of condition of the type

$$T - 21415^{d}427 = A + B(E - 5457)$$

The normal equations deduced are

$$-27^{d}.763 = +81A - 32B$$
$$+96994015.568 = -32A + 111370117B$$

From these are derived the values

$$A = +0^d.00131 \text{ with weight } 81$$
$$B = +0.87091599 \text{ with weight } 111370104$$

The residuals in the equations of condition give the probable errors

$$\pm 0^d.00612 \text{ for the unit of weight}$$
$$\pm 0.00068 \text{ in } A$$
$$\pm 0.00000058 \text{ in } B$$

and reintroducing the constants used in forming the equations of condition, we obtain the formula

$$\text{Minimum} = \text{J.D. } 2416662.8398 + 0^d.8709160\ E,$$

in which the computed times of minima are subject to the probable errors

$\pm 0^d.0032$ for $E =$ 0, first observation
± 0.0007 for $E =$ 5457, best determined minimum
± 0.0009 for $E =$ 6501, first minimum in 1920
± 0.0019 for $E =$ 8599, first minimum in 1925
± 0.0031 for $E =$ 10695, first minimum in 1930

TABLE III

PHOTOGRAPHIC OBSERVATIONS

Plate A. M	Date	J.D. 2410000+	Comp. Min.	Observation
2790.....	1904, June 30	6662.828	.840	Variable faint
2791.....	June 30	6662.874	.840	Variable faint
2798.....	July 1	6663.841	.711	Variable bright
2810.....	July 5	6667.862	.194	Variable bright
2889.....	July 30	6692.708	.451	Variable bright
3852.....	1905, Sept. 6	7095.656	.685	Variable somewhat faint
3868.....	Sept. 8	7097.755	.427	Variable bright
3901.....	Sept. 19	7108.743	.749	Variable faint
4477.....	1906, Aug. 8	7431.833	.859	Variable faint

The representation of the observations by these elements is thoroughly satisfactory. The lower of each pair of numbers in the column "Geocentric Min." of Table II is the computed time

of minimum derived from the foregoing formula. The agreement with the plates given in Table III is not quite so close, but when it is remembered that the photographic observations were generally exposures of an hour, while the eclipse lasts barely four hours, with the marked decrease in brightness lasting only two hours, it seems remarkable that the variation was discovered at all.

With the period given above the visual observations during and near eclipse were collected and plotted, and the light-curve was drawn, again assuming symmetry. The plot obtained is

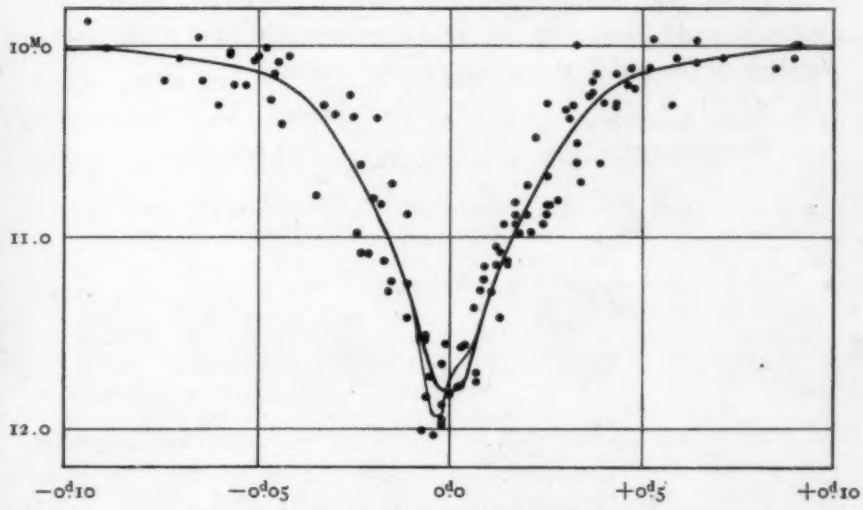

FIG. 1.—Light-curve of V Tucanae

reproduced in the accompanying figure. From the form of the light-curve it appears that the eclipse is partial, and near mid-eclipse the variation is exceedingly rapid, amounting to half a magnitude in twelve minutes.

SUMMARY

From 148 visual comparisons of V Tucanae with neighboring stars the eclipsing type of variation was confirmed, and a period of 0.8709 day was deduced.

A combination of these observations with the original Arequipa plates observed by Miss Cannon has enabled the writer to deduce

a formula for time of minimum which will be sufficiently accurate for a considerable time to come.

The period deduced from the visual observations of 1917–18 agrees with that deduced from all the observations within the probable error of the former, indicating that the period is sensibly constant.

The light-curve indicates a partial eclipse lasting 0.18 day, with a loss of light amounting to 1.8 magnitudes of the scale employed.

Lack of photometric data has made it necessary to use an arbitrary scale, rendering the light-curve unsuitable for the computation of the physical elements of the system.

La Plata, Argentina
September 1918

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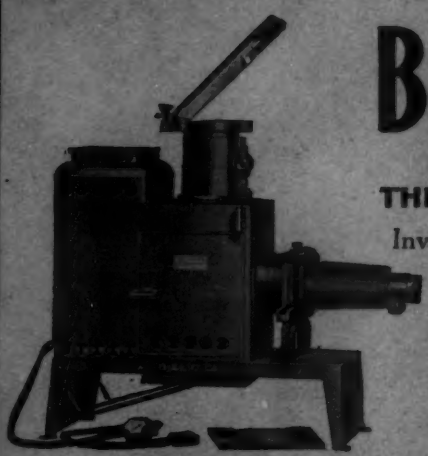

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